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## ON THE SUPPOSED OCCURRENCE OF SEEDLING INFECTION OF WHEAT BY MEANS OF RUSTED GRAINS

BY W. L. WATERHOUSE, B.Sc., AGR.,

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of Science and Technology.)*

AN important paper by Hungerford has recently appeared in the *Jour. Ag. Research*, vol. XIX. 15 June, 1920, p. 257, dealing with "Rust in Seed Wheat in Relation to Seedling Infection." As the result of careful and exhaustive experiments he states that, contrary to results reported by a number of previous workers, "stemrust (*Puccinia graminis tritici*, E. and H.) is not transmitted from one wheat crop to the next by means of infected seed grain. Further, in the writer's judgment, the occurrence of stemrust sori in the pericarp of the caryopses of grains and grasses has no especial significance, but the infection spreads to these tissues just as it does from an infection point in any of the vegetative parts of the plant" (p. 275).

The same writer gives a comprehensive summary of past work on this question and a full bibliography.

The present investigation was undertaken to see whether a histological examination of rusted grains during germination and the early stages of growth would throw any light on the problem. The results obtained confirm Hungerford's work and are briefly reported here.

In April, 1920, grain was obtained from a crop of wheat which was grown in Pembrokeshire in 1919 and badly rusted. Stubble left in the field was frequently found black with teleutosori, which were also abundant on awns, chaff and fragments of the rachis found mixed with the grain. The presence of teleutosori at the hilum end of a number of grains was determined and these grains were picked out. Several counts showed the percentage of rusted grain in the sample to vary from about 0.5 to 1.0 per cent. of the whole. The percentage of abnormal grains of a scabby nature was higher than this, and spores of the *Fusarium* and *Helminthosporium* type were obtained in scrapings from some of these.

Of the rust-infected grains, one portion was subjected to the hot-water treatment, the other portion left untreated. As controls, similar portions of grain on which no sori could be detected were used, part being treated and part untreated. All were germinated at a temperature of 15-18° C., and when the shoots were about half an inch long, planted in pots which were kept in a glasshouse. There was no observable difference in the germination of the rusted and healthy grains. At intervals during germination and growth seedlings were removed and portions of them fixed in Flemming's weaker solution, embedded and sectioned. The plants were under observation for a period of three months, during which time no rust appeared.

Sections of the infected grains showed that many of the numerous teleutosori at the hilum end were internal sori. In the germinating grains there was no indication of any development of the rust mycelium underlying the sori; furthermore, it had every appearance of being a dead mycelium as described by Hungerford. In many instances, irrespective of whether the original grain was rusted or healthy, treated or untreated, fungal hyphae were present in the developing seedling. They were generally of an intracellular nature. In one instance a *Fusarium* type of spore was noted in a mass of mycelium growing on the outer layers of the scutellum, and in other cases the hyphae belonged to a species of *Helminthosporium*, spores of this type occurring close to the outer masses of mycelium. Nothing in the nature of the "palmella-like" developments reported by Pritchard (*Phytopathology*, 1911, i. p. 150) was found. Cases were observed in which hyphae were present in the outer layers of the base of the seedling stem, but they were larger than rust hyphae and were intracellular in growth.

The above results are in close agreement with those recorded by Hungerford and further serve to show that it is extremely unlikely that rust mycelium in wheat grains brings about infection of the plant. The mycelium of other fungi is however often present in the developing plant and it might be mistaken for that of a rust.

(Received March 4th, 1921.)

## SOME PROBLEMS OF ECONOMIC BIOLOGY IN EAST AFRICA (KENYA COLONY)

By W. J. DOWSON,

*Royal Horticultural Society's Gardens, Wisley.*

(With 1 Text-figure.)

### I. INTRODUCTION.

THE effect of meteorological conditions on the relations between the host and its parasites has received little attention at the hands of the pathologist, but in a country like East Africa it supplies the key to the solution of the problem concerning the severity of attack.

For an understanding of the problems which confront the economic botanist and the agricultural entomologist it is essential to gain some knowledge of the physiographical and climatic conditions of this part of Africa, conditions so varied in extremes as to affect both host and parasite to a marked degree. The Kenya Colony is situated between the 4th parallel N. latitude and the 4th parallel S. latitude, has an area nearly twice that of the United Kingdom, but a population which cannot amount to more than 5 millions. The equator passes through the northern slopes of Mount Kenya, the glacier-covered peak of which rises a few miles south to a height of 17,000 odd feet. 120 miles due south of Kenya and just within Tanganyika Territory is Mount Kilimanjaro, whose summit rises 19,000 odd feet above sea level; and 120 miles W.N.W. from Kenya, and on the boundary line separating Uganda from East Africa lies Mount Elgon, 14,000 feet in height. The snow line is situated at an altitude of 15,000 feet above sea level.

These numbers are apt to give an exaggerated impression of altitude, for the height of all the Central African mountains from the general level of the surrounding country is considerably less because they rise from plateaux and uplands of 5000 to 7000 feet. Thus the highest point of Kenya from the general level of the surrounding country is, roughly, 11,000 feet.

Running north and south right through the country is the Great Rift Valley, one branch of which stretches from Lake Rudolph in the north

to Kilimanjaro in the south. This is the shorter arm of the Great Rift; the other, and longer, passes to the westward and embraces lakes Tanganyika and Nyassa.

The Uganda Railway crosses the Rift Valley at an angle and at the point where it crosses the two escarpments, the western or Mau escarpment is slightly higher (8320 feet) than the eastern or Kikuyu escarpment which is just under 8000 feet (see vertical diagram). Along the western rim of the escarpment between latitude 0 and 1 S. lies the Aberdare range which runs for a distance of 30 miles due north and south, and attains a height of 13,000 feet. The average height of the two escarpments is between 2000 and 3000 feet above the floor of the valley, itself some 6000 to 7000 feet above sea level, where it is crossed by the railway. The drop is always steep and in some places almost precipitous. It will be seen from the diagram that the land rises rapidly from the coast and that

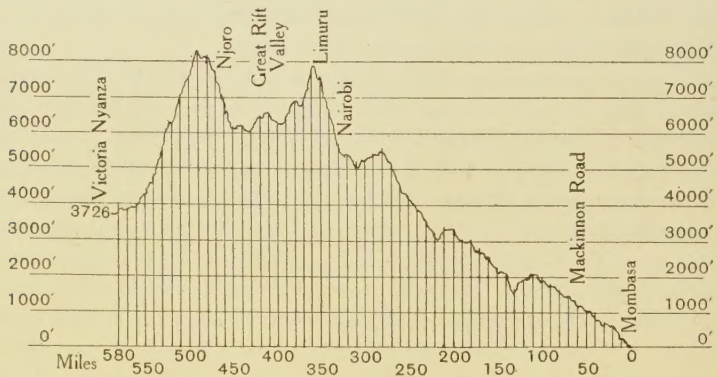


Fig. 1. Vertical diagram of Uganda Railway.

a comparatively short distance along the railway in the direction of Victoria Nyanza the altitude increases very considerably. The meteorological conditions along the course of the railway are very varied. Thus at Mombasa the annual rainfall is between 60 and 70 inches, but 60 miles inland, at Mackinnon Road Station (1300 feet) the average fall is not much more than 10 inches. Again Nairobi (5500 feet) has an annual rainfall of 30 inches, but 25 miles farther along the line Limuru (7500 feet) records an average rainfall of 70 inches. The different climatic conditions at these two places as a result of altitude are remarkable and exert a marked influence upon the spread of fungous diseases.

It is proposed to discuss shortly the most important problems of the

economic biologist, and to consider each plant or crop in the order which one naturally comes across it when travelling on the Uganda Railway from Mombasa to the Victoria Nyanza.

The writer wishes to acknowledge his indebtedness to the Entomological Division of the Agricultural Department at Nairobi for the knowledge acquired concerning insect pests.

## II. THE COCOANUT PALM.

The rainfall along the coastal belt is between 60 and 70 inches, but towards the S.E. corner in the neighbourhood of Shimoni the rainfall is greater, and besides such indigenous palms as *Hyphaene thebaica*, *Borassus flabellifer* and *Cocos nucifer*, a small patch of the oil palm *Elaeis guineensis* occurs. The rains are distributed in two seasons, a short one in November and a longer period from April to June. Along this coastal strip and for about 20 miles inland cocoanut palms are grown in plantations owned by Swahilis, Arabs, Indians and Europeans. The palms are subject to numerous diseases and pests, the most important of which are undoubtedly the bud-rot or heart-rot, and the cocoanut beetle (*Oryctes monoceros*). In the first, the infection can be traced from the upper external portion of the youngest folded leaf, but whether primarily due to *Phytophthora palmivora* Butl. or to bacteria was not ascertained. The dried and wilted upper portion of the spear contained much mycelium, but towards the actual rotting margin no hyphae were discovered.

Unlike most countries in which bud-rot has been recorded, the palm in East Africa is attacked at the bearing age, seven years, and very considerable loss is thereby caused to owners of large plantations in which several hundreds of acres have been planted out at one time. To the north of Mombasa, on an extensive plantation in which African and Ceylon nuts had been planted, 60 per cent. of the young Ceylon palms were attacked and killed in three years, and so susceptible did these imported palms prove that the rest were taken out and replaced with sisal hemp. The African palms appeared much more resistant, thus indicating that the disease, as it exists in East Africa, is probably native to that country, and has not been imported. Besides the high susceptibility of imported palms and the comparative resistance of native palms, three other points are worthy of notice. One is the striking fact that palms are only found in certain places and have never been known to thrive in others. Thus along the coast south of Mombasa on the Gazi Road, palms grow in patches which alternate with strips of country apparently similar in all other respects but upon which there are no palms.

The palm patches are mostly cultivated, are owned by natives, and alternate with areas of bush, forest or grass. The oldest natives in the district state that their ancestors tried to grow cocoanuts on these places but invariably failed. It is usually only these palmless areas which can be acquired, and in a number of instances it has been found that the cocoanut will not thrive in such.

On the other hand it has frequently happened with plantations of a permanent crop such as cocoanuts, coffee and citrus, that the first European holder of the land, in order to save time and expense, and to ensure a "quick return," has hastily ploughed and planted with immature seed or weak plants. These grow for a time according to circumstances, and to the new-comer, who is looking for a plantation already laid out, they appear in good condition. The original holder sells his plantation at a handsome profit on his outlay and is heard of no more. It is usually later when the crop should be bearing that serious trouble commences, and such cases are some of the most difficult with which the economic biologist is confronted.

The third point which is important in any consideration of the bud-rot disease is the state of cultivation in which the plantation is kept. On a certain plantation in which bud-rot had been recorded since 1912, those palms in the camp for native labour were not only of greater size and of more healthy appearance than those in the plantation, but in addition bore fruit earlier (5-6 years) and never showed a sign of the disease. It was only among the palms outside of the encampment that the disease appeared. These had been planted at the same season, and the only obvious difference between them was in their subsequent treatment. The camp had been kept scrupulously clean, no growth between the huts, and therefore between the palms, was allowed, and rubbish which might collect from food was never left lying about. On the other hand, but a few yards away from the camp, the ground was only weeded occasionally, as the supply of labour allowed, and then only between the palms and not underneath them. The idea seemed to prevail that hoeing up grass and weeds from the spaces between the palms and putting this to rot on top of the weeds growing at the foot of each tree, would produce excellent tilth. In reality, this procedure gave rise to the formation of the most favourable breeding-ground for all manner of fungi and insects—not to mention the non-aeration of the root system.

Among insect enemies, mention must be made of the rhinoceros beetle (*Oryctes monoceros* Oliv.). This large beetle, nearly 2 inches long, flies mostly at night and feeds on the tender tissues of the youngest

unfolded leaf. The edge of the leaf is not eaten away but a cylindrical hole is eaten out, the diameter of the beetle's body, from one side to the innermost soft tissues, passing through each leaflet in turn. Consequently, when the leaf unfolds a circular rent appears in each leaflet, the line of holes being nearly straight. Very often the beetle manages to bore through the midrib, in which case the end of the leaf falls over and rots away. The pest can be so bad that nearly all the leaves present these lines of holes with a number of the tips fallen over. Occasionally the beetle eats the hole near enough to the growing point of the palm as to be the means of starting a heart-rot which in its effects upon the palm is similar to the bud-rot.

Effective measures of controlling this pest were only devised after the life-history of the beetle had been discovered. The female beetle lays her eggs in old rotting stumps of the cocoanut palm or other trees in the vicinity. Hence the idea arose of making beetle egg traps and, as the results have shown, these have proved fairly successful if regularly inspected. The traps are made by collecting all the old stumps and decaying vegetation and packing them in pits in the neighbourhood of the palms. The pits are roughly 2 feet deep and 10 feet across. It is important to destroy all the rest of the rotting stumps and vegetation not used in the construction of the traps, which would be used by the beetles to lay their eggs. At regular intervals the traps are inspected, and when found to contain a goodly number of larvae, a covering of sand is placed over them and carbon bisulphide is injected into each, thus killing the larvae.

### III. SISAL HEMP.

Besides the cocoanut palm, sisal hemp, *Agave rigida*, var. *sisalana*, is also grown in extensive plantations along the coastal belt. This plant has borne in the past the reputation of being the only crop in East Africa which possessed no enemies. Sisal was first introduced in 1895 in the form of bulbils from Yucatan by the Germans into German East Africa (now Tanganyika Territory).

In the extremely dry conditions of Yucatan the plant grows for twenty or more years before producing its single inflorescence, after which it dies down. Owing to this slow growth but few leaves are formed each year, and hence only a few can be cut annually from each plant for the decortication of the fibre. In Yucatan it is possible to make use of the waste which is washed away by a stream of water and which contains a considerable amount of sugar. The liquid is filtered and fermented to produce a strong alcoholic drink.

In East Africa owing to the very much moister conditions the plant reaches maturity far sooner and flowers and dies in its fourth year. The leaves, which are ready for cutting at the end of three years, contain very much less sugar, and it was found on analysis that even in the dry season not sufficient sugar was present to render the fermentation of the waste practicable, without going to the expense of concentrating the liquid first. So far, no sisal planter has seen his way to do this, and the subject has received no further attention, though without doubt both sisal waste and coffee berry pulp could be utilised for the production of alcohol.

In a very wet rainy season at the coast the ring-spot disease, due to *Colletotrichum agaves* Cav., has been recorded, and nearly always under such conditions a sun-scorch also takes place in which large irregular patches, red in colour, are produced, rendering decortication difficult or impossible. The spores of *Colletotrichum agaves* can be disseminated by air currents. During the rainy season when this disease appeared at the coastal plantations, a yellow bacterial blotch occurred in a plantation near Nairobi and by the amount of gum produced in the tissues decortication was rendered impossible. The sunken yellow areas were produced on the upper half of the leaves and varied greatly in size, from a small speck to a patch several inches in length. The bacteria entered through the stomata and the organism, a bacillus, was isolated and produced the disease by inoculation, but was not studied in detail. The blotch ceased to spread on the cessation of the rains and is not likely to cause much damage except in a prolonged and abnormally heavy rainy season.

No damage as yet has been caused by insects, but larger beasts such as the porcupine do, in certain parts, cause considerable loss by eating off the entire tops of young plants, thus reducing the length of the leaves and consequently the fibre.

#### IV. COFFEE.

Coffee growing is one of the staple industries of the highlands of East Africa, and has steadily increased since *Coffea arabica* L. was first planted by missionaries a quarter of a century ago. Of native coffee, only one occurs in the country, namely, *C. nandiensis*, which is found on the steep banks of rivers at an altitude of over 7000 feet and is a shade-loving plant. *C. robusta* is the native coffee of Uganda. It is to be noted that there is no resting period such as occurs in Rhodesia, where once every year all the leaves fall from the tree. In East Africa coffee is not deciduous, but is continually producing more leaves, rapidly during the rains,

much more slowly in the dry season. Both *C. arabica* and *C. nandiensis* are subject to a number of fungous and insect enemies. Meteorological conditions play a most important part in the severity of attack of both fungi and insects, particularly so in the coffee leaf disease due to the rust *Hemileia vastatrix* B. & Br.

So far as the writer is aware, coffee cultivation in the eastern hemisphere, including Africa, has always been intimately connected with that of *Hemileia*, and has usually resulted in the ascendancy of the parasite sooner or later. This does not necessarily mean that the coffee trees are threatened with destruction as was the case in Ceylon, but it does mean that *Hemileia* is slowly spreading in all those countries in which coffee is grown, with the present exception of the highlands of East Africa.

It is hoped to deal with the subject of coffee leaf disease in Central and Eastern Africa in more detail in a further paper. For the present purpose, some observations of the disease as it is now found in the highlands of Kenya Colony will suffice.

The first observation of importance is that only once in Africa and in Ceylon have the teleutospores of the parasite been found. It is a curious and as yet an unexplained fact that since Marshall Ward worked out the life-history of the fungus in Ceylon, and a German observer reported the presence of teleutospores on some African specimens of the disease not long afterwards, these spores have never been observed since. The likelihood, therefore, of the existence of an aecidial stage on some other plant is not very great. Coffee leaf disease, like many other rusts, is propagated in the countries in which it is found by the uredospores only.

The second observation to be recorded is, that the first attack of *Hemileia* is undoubtedly the most severe; subsequent attacks, other things being equal, are less marked in intensity. Nearly all the trees are badly infected, but in well-kept plantations only a small percentage of the leaves actually fall, although the lives of the others are considerably curtailed. Entire defoliation never takes place, and subsequent attacks are less severe, that is to say, not so many pustules of uredo-sori are formed and not so many leaves are infected. That the general health of the trees has much to do with the severity of the attack is obvious when an ill-kept plantation is compared with others better cared for in the vicinity at any season of the year. The initial preparation of the ground, the proper planting of the seedlings, pruning and the amount of berries the trees are allowed to carry, are all factors which influence the resistance of the host.

The third and perhaps most important observation is the effect of altitude and, therefore, of temperature both on the tree and on *Hemileia*. At the Mission Station of Bura near the coast, at an altitude of nearly 2000 feet, the annual rainfall is about 50 inches and the temperature about 75–80° F. both day and night. The atmosphere is therefore warm and moist, conditions favourable to the luxuriant growth of coffee, but much more so to *Hemileia vastatrix* which has destroyed the coffee plantation attached to the Mission. In the neighbourhood of Nairobi the general altitude of the plantations lies between 5000 feet and 6000 feet, and the rainfall of the district averages 30 inches. The atmosphere is therefore dry, although it is to be noted that very heavy dews are precipitated at night, and it is in this dew that the uredospores usually germinate. The temperature is never very high, and rarely exceeds 75° F., dropping again at night to the region of 50–40° F. and sometimes lower. The atmospheric conditions are warm but not moist and the general balance of conditions is less favourable to the spread of *Hemileia* than to the growth of coffee. Ten miles to the north-west of Nairobi in the Limuru district very different conditions prevail. The altitude is greater, between 6000 and 7000 feet, and hence the climate is colder on the whole. On the other hand, the rainfall is much greater, averaging between 60 and 70 inches. The atmosphere is saturated in the mornings and a "Scotch mist" is the normal experience. The climatic conditions at Limuru, therefore, are the reverse of those 10 miles away, and a moist but comparatively colder atmosphere prevails. Coffee under these conditions is not so luxuriant in growth, is slower but more hardy. *Hemileia* is prevalent throughout the district but is scarce; the first attack is the worst as is the case at lower altitudes, but it is nothing like so severe, and in well-kept plantations in a normal season the rust has to be searched for.

The conditions then which prevail at altitudes of 6000 to 7000 feet are still favourable to coffee but very much less so to *Hemileia* and the limiting factor to the rapid spread of the disease is temperature. At such altitudes the temperature is too low for the parasite to flourish.

It has been pointed out that subsequent attacks of the rust are less severe than the first, which means that the coffee trees acquire a certain power of resistance, or become less susceptible after the initial attack. That this partial immunity is not due to a lessening of the virulence of the parasite is demonstrated by the fact that a hitherto unattacked plantation in the vicinity of others which have been already visited is much more severely infected when *Hemileia* is present on all at the same

time. The virulence of the fungus remains the same, the resistance of the host increases.

Under such conditions, spraying for leaf disease has proved successful at altitudes of 5000 to 7000 feet. Any dilute fungicide has been found by experiment not only to control the disease but, if applied at the right time, to completely eradicate it from plantations. The usual time for spraying is just before the long rains commence, and again at their termination. Reinfection usually takes place in subsequent seasons by reason of wind-blown uredospores from a plantation which has *not* been sprayed. In the Limuru district the disease does such little damage that spraying, always an expensive business, has not been resorted to. The most popular fungicide, and one easily made up, is known locally as "carbide," and is prepared by adding 12 ozs. of calcium carbide to 40 gallons of a solution containing 2 lbs. of copper sulphate in water. At lower altitudes, *e.g.* between 4000 and 5000 feet, spraying with such dilute fungicides is of no avail; but with a stronger mixture containing 4 lbs. of copper sulphate and 24 ozs. of calcium carbide per 40 gallons, the results are much more encouraging, particularly on well-cultivated plantations. At such altitudes it is essential to spray regularly to keep *Hemileia* in check. Below 4000 feet, if the rainfall is at all suitable for the growing of coffee, the other factor of temperature is so much more favourable to the rapid spread of *Hemileia* that the disease cannot be controlled by any known method, and on account of this, coffee growing is rendered unprofitable at such altitudes.

Of other fungous diseases of coffee, mention may be made of the leaf and berry spot due to the attacks of *Cercospora coffeicola* B. & Cke. Considerable damage has been caused by this fungus on neglected plantations, and cases have occurred in which defoliation has resulted. On the berries it is rather more serious from the planter's point of view, as the affected fruits cannot be pulped clean. This trouble is more prevalent during unusually heavy and prolonged rains but can always be found on ill-cared for plantations either on the leaves at any time, or on the berries as they commence to turn red. The disease is easily controlled by spraying either with the "carbide" mixture mentioned above, or with Bordeaux mixture containing 2 lbs. of copper sulphate per 40 gallons.

Quite recently a berry spot has occurred due to infection by a species of *Septoria*, which in its effects on the fruit is similar to that produced by *Cercospora coffeicola*, but it is not known whether this species is identical with *S. maculosa* (Berk.) Cke. recorded on coffee berries from Venezuela. The disease is more common on low lying heavy soil, and is

quite liable to cause considerable damage unless checked by spraying when the berries are still green.

Rot of the roots is not very common, and wherever it occurs usually indicates that the ground has not been properly prepared at the start, and that stumps and roots of native trees have been left in the soil. These are always sources of infection by root destroying fungi, the mycelium of which spreads from the decaying stumps through the soil on to the roots of the coffee trees.

Dieback of the branches is troublesome in certain parts of the country, particularly where the rainfall is more than 45 inches and the soil is heavy. Up to the present this trouble is not fully understood, but among various contributory causes rendering the trees liable to this disease are unhealthy conditions of cultivation, water-logged soil, attacks of *Hemileia*, overleafing, insufficient pruning, and the presence of *Colletotrichum coffeanum* Noack.

Dieback is far more prevalent in Uganda where the general conditions are not so favourable to coffee as they are in the highlands of East Africa. A very singular dieback of the main stem has occurred more than once in nearly every coffee district and has so far baffled any attempts to elucidate its true cause. Nearly every case of the disease was reported shortly after a heavy thunder-storm had passed over the plantations, and was at first ascribed to lightning. Circular patches of trees from 20 to 50 in number were discovered with shrivelled and blackened foliage; and there was always one tree in the centre which was more affected than the rest. The least affected were on the outside, and intermediate stages occurred between. The shoots bearing the blackened leaves were dead towards the tips and for some distance down each shoot, including the main stem, the cortex was discoloured and the cambium disorganised. Unless the affected parts were cut off well below the discoloration in the cortex the trees invariably died slowly back to the roots.

On old specimens which had thus died, the cambium had been replaced by a brown mycelium and very often the fructifications of a *Diplodia* were found on the bark, and always the pycnidia of a *Phoma* and a *Phomopsis*. At one time it was considered that this particular form of dieback was due in the first place to the *Phoma* or to the *Phomopsis*, but the few inoculation experiments which could be carried out did not lend support to this view.

The problem is an interesting one of some economic importance and calls for a more thorough investigation than has hitherto been possible into the relations existing between the abnormal meteorological con-

ditions, the suddenness of the withering, the rapid disorganising of the cortical tissues and the presence of the three parasitic fungi mentioned above.

The insect pests of coffee are more serious than are the parasitic fungi, and mention may be made of at least two which have been computed to cause more annual loss than perhaps any other disease to which coffee is subject. The variegated bug, *Antestia lineaticollis* Stål., has been known almost from the commencement of coffee planting throughout Africa. The insect punctures all the young growing parts of the tree, but chiefly the very young flower buds which are formed in whorls in the axils of the leaves. The result is a non-formation of flowers and a proliferation of shoots in their place, thus bringing about an almost total failure to set fruit and causing much additional labour and expense in pruning. *Antestia* also pierces and sucks the green berries producing a stain upon the kernels which considerably lessens their market value. As is usual with such insects, spraying either with a stomach poison or a contact insecticide is of no avail. The bug is active and either hides under leaves and crevices, or flies to the ground where it becomes invisible owing to its colour. In the past the usual method of combating this pest was the collecting by hand of the bugs, but recent knowledge of the life-history has indicated a more effective way of controlling the numbers of the insect. The eggs are laid in clusters of a dozen on the underside of the leaves and are normally pearly white in colour. A large number of eggs are not white but grey, and out of these hatch out, not young *Antestia* bugs but minute chalcids. Two species of these have been discovered which parasitise the eggs of *Antestia*, and it has been found possible on the Government Experimental Farm near Nairobi to breed the parasites in the laboratory in such numbers as to completely check the increase of *Antestia*. It is hoped in time to be able to distribute the parasite early enough to those plantations which show signs of the pest to prevent the insect from doing appreciable harm.

Another serious insect pest is comparatively new, having first made its appearance in 1915, and is a species of *Diathrothrips* (*D. coffeae* Will.). This minute insect appeared in the dry season of 1915 in clouds, and, settling upon the coffee trees of a plantation close to Nairobi, sucked every green part almost dry, producing a conspicuous silvery appearance of the foliage. The trees were entirely defoliated, and in some instances killed. From the Nairobi area the pest gradually spread in a north westerly direction and is approaching Uganda. As in the case of *Antestia*, no known spraying fluid is of the least avail, for at the first contact of an

insecticide the great majority of insects fly into the air and hover over the trees in a cloud. They cannot, however, stand heavy rains, and shortly after these commence the pest disappears. The insect appears in very large numbers only in a prolonged dry season and then reigns supreme until the next rains clear it off again. Where it originally came from, its life-history, and what becomes of it during the rains, are problems still awaiting solution.

A third pest, which is often responsible for a large amount of re-planting, is the cut-worm, a larva of various species of the moths *Agrotis* and *Euxoa*. *E. segetum* is the most common. Newly planted out seedlings are very subject to attack and are girdled just below ground level. Gathering by hand, and the protection of the young stem by a band of some durable substance soaked in grease, are the methods employed in controlling this pest. Baits of chopped grass sprinkled with Paris Green have not proved very effective.

The remarks relating to the sound cultivation of the cocoanut palm are equally applicable to coffee and indeed to any permanent crop.

Finally, as regards coffee, it is a point of considerable interest to compare the yield of the East African crop with that of other countries of the East. In the best days of Ceylon coffee the heaviest yield was not more than  $\frac{1}{2}$  ton to the acre, and the average was rather below this. In East Africa the average yield is greater; over a ton has been recorded more than once, and  $\frac{3}{4}$  ton to the acre is not considered an excessively heavy crop. Latterly, however, it has been found by experience that the trees do better, are not so exhausted and are therefore more capable of withstanding disease, if the crop is limited to not more than  $\frac{1}{2}$  ton to the acre. This can be done by stripping off some of the young fruits soon after they have set.

## V. THE FORESTS OF THE HIGHLANDS.

The forest areas of East Africa are not very numerous but are of considerable extent, the most important for valuable timber being those of the Highlands at altitudes ranging from 6000 to 8000 feet. Of the many different trees which yield good timber only a few are used at present to any great extent. The yellow wood, *Podocarpus gracilior*, and the so-called East African Cedar, *Juniperus procera*, are used extensively in building. The m'hugu, *Brachylaena hutchinsi*, a giant member of the Compositae, is largely used for fuel, and for fencing and telegraph poles as white ants do not attack its wood.

*Podocarpus*, so far, has no fungous enemies; its timber, however, is very much attacked by termites. *Juniperus procera* is subject to the attacks of the bracket fungus *Fomes juniperinus* (Schrenk.) Sacc. & Syd., which causes very great damage by producing a heart-rot. About 70 per cent. of the trees are affected, and it is quite common to see newly felled trunks with a large part of the wood replaced by spongy red masses extending for considerable distances. *Fomes juniperinus* is probably a wound parasite, the hoof-like fructifications of which are usually formed just below a small branch which has been broken off a long time previously and which has not been occluded over. The heart wood of *Juniperus procera* is resistant to the attack of white ants.

*Brachylaena hutchinsi*, a tall tree with a straight trunk, is often killed by strangulation brought about by the entwining and anastomosing branches of a species of fig. This fig gradually surrounds the trunk of its host and all stages are commonly met with, from the partially grown fig at the base of its victim to the nearly fully matured parasite with its rounded head of foliage, out of which can just be distinguished the top-most branches of the *Brachylaena*, evidently in extremis. Finally a stage is reached in which the m'hugu rots away leaving the fig standing alone, and soon afterwards the fig itself dies.

Recently, an important *Sclerotinia* disease of the young seedlings of *Brachylaena* in the nurseries of the Forestry Department near Nairobi has been recorded and partially investigated. The young trees were found to wither and die when they had reached a height of from 3 to 4 feet. An examination of the roots brought to light numerous small black sclerotia, irregular in shape, clinging to the base of the stem just below ground level. The sclerotia varied in size from a rounded mass 1 mm. in diameter to a flat irregularly shaped mass 1 cm. across. Several specimens of the sclerotia were collected and kept under conditions as natural as possible, and after a few months began to produce apothecia on long ( $\frac{1}{2}$  in.) stalks. None, however, succeeded in reaching maturity, and when nearly fully opened, withered and died down. On investigation these nearly ripe apothecia were discovered to be infested by eelworm, and the question arises as to whether or not in nature the spread of this fungus is kept in check by the eelworm. The investigation could not be completed and the few apothecia produced in the places where the infected trees had been removed likewise succumbed to eelworm attack.

## VI. CITRUS.

The lime is found wild along the coast, probably introduced from the east by the early Portuguese settlers, while the excellent greenish orange of Zanzibar was probably planted by the early Arab traders.

At the present time all varieties of citrus are grown, generally from budded stocks imported mostly from South Africa, and at one time it was thought possible to export the fruit to England. Oranges, lemons, grape-fruit, etc. might be placed on the English market at a time when no citrus fruits from other countries were available. Partly because of heavy sea freights *via* the Cape, and still more heavy Suez Canal dues, and also because the comparatively young plantations of the Highlands are still producing rather thick-skinned and not very juicy fruits, the attempt has not yet been made. Those plantations which have been raised from seed bear very much better fruit but take longer to reach this stage, namely, eight years as against three years from budded stocks. Very much better fruit is produced at lower elevations such as 3000 to 4000 feet. A few factories have been started for the extraction of citric acid.

Perhaps the most serious disease, if not the most common, is the foot-rot or mal-di-goma, generally ascribed to the attack of *Fusarium limonis* Briozzi, but which is more likely due to bacteria in the first place. The *Fusarium* is probably secondary and gains entrance through the cracks of the bark brought about by the activity of the bacteria.

Various bacterial leaf spots, but not the Citrus Canker of the Gulf States and South Africa, are common and usually make their appearance in the dry season, causing considerable damage by defoliation. This is particularly the case in a neglected grove or one in an unsuitable situation, such as a stiff soil apt to be water-logged in the rains. The most common form which the spot disease takes is large concentric rings of small blisters, hard in texture and brown in colour.

As regards insect pests, citrus in East Africa is an outstanding example of the introduction of pests into a country on the imported hosts. Both the Australian bug, or fluted scale, *Icerya purchasi* Mask., and the California red scale, *Aspidiotus aurantii* Mask., have been introduced in this manner. Considerable loss has been caused by both, but more particularly by the former, which does not confine itself to citrus and will infest almost all other woody plants, as for instance coffee, roses, black wattle (*Acacia*). No insecticide has yet been devised which will control this scale effectively. Fortunately, however, there is an African

lady-bird beetle, the larva of which will devour the *Icerya* and helps to check to some extent the damage caused by this insect. A resin soda spray has been employed with good results against the *Aspidiotus*, but it is now the endeavour of the Government to destroy all trees infected by the red scale and to replace them with healthy young stock.

## VII. WHEAT.

Wheat, like coffee, affords another instance of the variable relations existing between host and parasite under different climatic conditions. For the purpose of the present paper it will prove useful to contrast the relation of the rust fungi to wheat in three widely separated countries such as England, East Africa and Australia. In all three countries the same three rusts attack wheat, namely, the black stem rust (*Puccinia graminis* Pers.), the yellow rust (*Puccinia glumarum* Eriks. & Henn.), and the brown or leaf rust (*Puccinia triticea* Eriks.). In England *Puccinia glumarum* is the commonest and most destructive; in Australia *Puccinia triticea* causes most damage because of its very early appearance in the season, wheat when only a few inches high in New South Wales being attacked. In East Africa the greatest destruction is due to *Puccinia graminis*, while in addition to this, *Puccinia glumarum* is very common on certain wheats of Egyptian origin. These two rusts usually, and *Puccinia triticea* nearly always, appear late in the season, generally after the wheat has come into flower. Hence it will be seen that the problem of controlling rust in wheat in East Africa differs from that in the other two countries mentioned. Climatic conditions also influence very considerably not only the growing of the wheat but also the spread of the rust. Thus at Nairobi there are two rainy seasons in the year, during both of which it is possible to grow early maturing varieties of wheat. The fact that it is necessary to employ varieties which mature early, that is, in four to five months, because of the shortness of the seasons, makes it possible to grow with success such varieties as escape the rust attack on account of this character. As an instance of this, the Australian wheat "Florence" may be cited, which at Nairobi was found to mature in four months after sowing. "Florence" is not a rust resistant variety, but when sown early enough escapes the rust attack. This was demonstrated at the Experimental Farm near Nairobi where, during some of the trials, "Florence" and another Australian wheat, "Bobs," were sown in adjacent plots and at the same time. "Bobs" takes between six and seven months to ripen and always falls a victim to the attacks of *Puccinia triticea* and *Puccinia graminis* which make their

appearance generally in the third month after sowing, so that for the last three months of growth "Bobs" has these two rusts to contend with. On the other hand, "Florence" is nearly ready to be reaped when the rust commences, and has reached a stage when the presence of rust can do but little or no damage. Had "Florence" been sown two months after "Bobs" so as to be ripe at the same time as the latter, it would have been attacked and badly damaged.

Another condition which plays an important part in the severity of the attack is the amount of nitrogen in the soil. In England, wheat, being an exhaustive crop, is usually grown on heavy land. In East Africa the great majority of soils contain a larger proportion of nitrogen than in England, and it has been shown by experiment that an excess of nitrogen renders wheat more susceptible to the attacks of rust. A very striking demonstration of this fact was provided unintentionally in a certain large field of wheat grown in the Highlands (Njoro) of East Africa. At a distance of a few hundred yards the wheat appeared brown in colour with the exception of a small green triangular patch in one corner. The brown colour was due to the presence of *Puccinia graminis* and *Puccinia triticina*, while the green patch was nearly free from rust. The wheat was the variety Rieti and had been sown all at the same time, but on the triangular patch flax had been grown the previous season. Following this observation, repeated trials were made at Nairobi with a susceptible wheat such as "Bobs," one block of which was sown on land which had borne a root crop the season before, and another block of "Bobs" on land which had previously carried flax. The wheat on the old flax land was rusted to a far less extent than that on land which had not borne flax. The explanation offered is that flax, itself a very exhaustive crop, removes from the soil that amount of nitrogen which would otherwise render the wheat very susceptible to the attack of rust. That this explanation is probably correct is borne out by the fact that wheat grown upon land which has previously carried beans is so badly affected by rust that in most cases the crop is almost destroyed. In this case the already high nitrogen content of the soil has been augmented by the activity of the nodule forming bacteria of the beans. It has been found that the following rotation of crops is an excellent one and produces satisfactory results: (1) Flax. (2) Wheat. (3) Beans. (4) Flax or Maize.

The attempt to breed rust resisting hybrids of wheat on Mendelian lines has met with a considerable measure of success, some of the selections so produced possessing such desirable characters as early maturity, good milling grain and "strong" flour. Of two of these varieties, Cross

No. 11 is a selection from the hybrid "Early Rieti" and "Red Fife," and has proved highly resistant to *Puccinia graminis* in all parts of the country so far tried. The other resulted from the cross "Egyptian No. 3" and "Nut Cut." "Egyptian No. 3" by itself was found to be very resistant to *Puccinia graminis* but susceptible to *Puccinia glumarum*, while the Australian "Nut Cut" was susceptible to *Puccinia graminis* but resistant to *Puccinia glumarum*. From the resulting hybrid Cross No. 13 was selected and was found highly resistant to both rusts.

#### VIII. FLAX.

Flax, which grows well in the Highlands, is subject to the attacks of numerous enemies, chief of which at the present time is the cut worm, the larva of certain moths. The loss caused by the depredations of this grub are enormous, whole fields being completely destroyed soon after the plants appear above the ground. Any spray which poisons the cut worms also kills the flax, and up to the present no method has been devised of coping with this most destructive pest. As has been noted, newly planted coffee is also very subject to the attentions of these larvae, but in some districts the pest is more prevalent than in others.

The mature flax plant is often attacked by a flax moth which lays its eggs in the ripening capsules so that considerable damage is caused in this way to flax grown for seed.

Of fungous diseases, the wilt caused by *Fusarium lini* Boll. is the most important and is commencing to spread in certain localities. The appearance of this disease is most probably due to imported seed bearing the conidia of the *Fusarium*, and its spread is undoubtedly the result of the present practice of growing two or even three crops on the same land without a break or rotation. Experiments designed to prevent the spread of the wilt by infected seed have been commenced, and although of a preliminary nature, have given unexpected results. As flax seed is extremely difficult to disinfect by the usual method of wetting with formalin solution, or with copper sulphate, by reason of its mucilaginous coat, it was thought possible that the desired result might be obtained by subjecting the seed to the action of formalin vapour. The first experiments were designed to find out what effect the action of the gas would have on the germinating power of the seed. Fresh seed from an uninfected area was treated for 4 hours, and the amount of formalin or the number of tablets was to be increased steadily until a marked effect on the germination of the seed was produced. After each experiment 200 seeds were counted out and placed in petri dishes to germinate. The

first two or three times this was done no effect either on the rate or on the amount of germination was apparent, the results showing 98 per cent. germination in 48 hours. Later, however, with a greater concentration of gas, the rate of germination was accelerated, 98 per cent. germination being obtained in 24 hours. This result was quite unlooked for, and is the reverse of what would be expected. The usual result of soaking seed, for instance coffee, in a solution of formalin (over night in a 0.3 per cent. solution) is to retard its germination from one month to anything up to three months according to the age of the seed. The effect of the gas on the *Fusarium* conidia was not tried owing to the absence of infected material at the time this work was started.

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## THE EXPERIMENTAL PRODUCTION OF WINGED FORMS IN AN APHID, *MYZUS RIBIS*, LINN.

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IT is well known that most Aphidini are dimorphic in respect of the viviparous parthenogenetic generations, which may be either winged or wingless; but the appearance of either form is determined by factors not yet understood. Failure of the food supply has been suggested by some authorities, but this view is based on general observation rather than on experiment. Börner<sup>(1)</sup> points out that in autumn *Rhopalosiphum lactucae* produces a host of apterous females whose attack causes the plant to sicken and die, and yet no winged forms appear. He also records some observations on the "hop louse," where a healthy plant produced more alate females than a sickly one.

In 1901 Clarke<sup>(2)</sup> cultivated the common rose aphid upon cuttings planted in sand saturated with solutions of various salts, and he recorded that a solution of magnesium salts resulted in the development of an abnormally high proportion of winged forms. I have not been able to obtain a copy of Clarke's paper, but his experiment was repeated in 1912 by Neill<sup>(3)</sup> with similar results, and has since been amplified and extended by Shinji<sup>(6)</sup>.

Shinji experimented with several species of aphides, and found that by watering the host-plants with solutions of certain substances, the proportion of winged forms produced might be as much as 100 per cent. He also records that other solutions had a contrary effect.

Among the "wing-producing substances" are included salts of magnesium, antimony, nickel, tin, zinc, and also sugar; while the list of "non-wing producing substances" contains tap-water, alcohol, tannin, urea, and salts of strontium, potassium, and calcium, etc. The aphides were susceptible to the treatment for three or more days after birth, according to the species.

In 1920, I had occasion to rear a number of generations of the red currant aphid (*Myzus ribis*) in connection with a statistical inquiry into variation. As the required characters appeared only in the winged female,

it was desirable to obtain a high proportion of these forms in each generation; therefore, I repeated Shinji's experiment. The numbers used were necessarily small, but since my results are not altogether in agreement with his, and as the subject is of some biological and economic interest, they are given here.

The aphid used is a common pest of red currant bushes, and, during the summer, also feeds facultatively on weeds such as *Lamium* and *Galeopsis*. An account of its life-cycle has been published elsewhere(4).

Cuttings of red currant were planted in nurseryman's sand previously washed for 24 hours in tap-water, which, according to Shinji, is one of the "non-wing producing" agents. A single stem mother or fundatrix was placed on each, and the young born were removed within 12 hours to similar cuttings watered either with tap-water, or else with an  $m/50$  solution of  $MgSO_4$ , the latter being about the optimum strength of this salt for wing production, according to Shinji's observations.

Table I.

|   | First Generation      |                       |                        |                   | Second Generation     |                       |                        |                   |
|---|-----------------------|-----------------------|------------------------|-------------------|-----------------------|-----------------------|------------------------|-------------------|
|   | Solution used on host | Number of individuals | Number of winged forms | % of winged forms | Solution used on host | Number of individuals | Number of winged forms | % of winged forms |
| A | { $H_2O$              | 24                    | 8                      | 33                | $H_2O$                | 250                   | 205                    | 82                |
|   | { $MgSO_4$            | 31                    | 23                     | 74                | $MgSO_4$              | 60                    | 18                     | 30                |
| B | $MgSO_4$              | 41                    | 26                     | 63                | —                     | —                     | —                      | —                 |
| C | $MgSO_4$              | 14                    | 10                     | 71                | $MgSO_4$              | 32                    | 25                     | 78                |
| D | $MgSO_4$              | 34                    | 11                     | 32                | $MgSO_4$              | 254                   | 167                    | 66                |
| E | $MgSO_4$              | 46                    | 2                      | 4                 | $MgSO_4$              | 80                    | 37                     | 46                |
| F | $MgSO_4$              | 21                    | 7                      | 33                | —                     | —                     | —                      | —                 |
| G | $MgSO_4$              | 30                    | 12                     | 40                | $H_2O$                | 40                    | 35                     | 87                |
| H | $H_2O$                | 10                    | 0                      | 0                 | $H_2O$                | 80                    | 61                     | 76                |
| I | $MgSO_4$              | 20                    | 14                     | 70                | —                     | —                     | —                      | —                 |
| J | $H_2O$                | 42                    | 38                     | 90                | —                     | —                     | —                      | —                 |

The results of the experiments are given in Table I. They were not carried further than the second generation since the object of the work was not primarily to repeat Shinji's experiments; and it was found that the proportion of winged forms in each strain was high in the first two generations, whether the salt solution was used or not. It will be seen that where  $MgSO_4$  was employed for the first generation, the percentage of winged individuals varies from 70 per cent. to 4 per cent. and that the highest proportion of all was obtained in strain J, where nothing but tap-water was used.

A second experiment was made in May. It was necessary, to ensure the continuance of certain strains, to transfer the third or fourth genera-

tion to a second host-plant, and the common Dead-nettle (*Lamium purpureum*) was selected for this purpose. Winged females of four different strains were transferred to potted plants of *Lamium*, watered with a  $m/20$  solution of  $MgSO_4$ . Their young were removed to currant cuttings, which, with the exception of one, accidentally left among a number of other plants watered with  $H_2O$ , were irrigated with the same solution. The numbers reared in this second experiment (Table II) were very small, as the mortality after transference from *Lamium* back to currant is high, but the only winged forms produced appeared on the plant watered with  $H_2O$ . This was probably due to chance, but it seems

Table II.

|      | Solution used<br>on host     | Number of<br>individuals | Number of<br>winged forms |
|------|------------------------------|--------------------------|---------------------------|
| I.   | {(a) $MgSO_4$<br>{(b) $H_2O$ | 6<br>7                   | 0<br>7                    |
| II.  | $MgSO_4$                     | 3                        | 0                         |
| III. | $MgSO_4$                     | 3                        | 0                         |
| IV.  | $MgSO_4$                     | 1                        | 0                         |

to show that the presence or absence of magnesium is not the only determining factor in wing production. It is important to have controls in experiments of this kind, for the appearance of a large number of winged forms in the first generation (Table I) might have been attributed to the salt solution used to irrigate the plant, if other strains, reared under identical conditions but without the magnesium sulphate, had not likewise produced a high proportion of these forms. Moreover, the proportion of winged forms among the magnesium treated broods varies considerably. The evidence points to the conclusion that, as regards this species at any rate, the appearance of alate females cannot be attributed wholly to the presence of magnesium salts, although it is quite possible that the aphides may react to metabolic changes in the host plant, induced by an abundance of such salts in the soil.

Gregory<sup>(3)</sup> found that the proportion of winged to wingless females in the broods of the pea aphid, *Microsiphum destructor*, could be raised by periodically starving the parent during its development. This lends some support to the view that exhaustion of the host-plant leads to the production of winged migrants which will seek fresh food supplies for the maintenance of the race; but it may be pointed out that periods of total abstinence, alternating with periods of normal feeding, would not necessarily produce the same effect as continuous feeding upon an inadequate diet.

Thus the results obtained by Gregory and Shinji are not wholly in agreement, and neither are altogether borne out by observations made in the field. Thus the maximum production of winged forms in many species takes place in the third and fourth generations when food is abundant, and then diminishes in a marked degree, although the apterous forms may continue to feed and reproduce on the same plant for the rest of the summer(4). If some of the winged females are induced to breed on their birth plant, the young, exposed to the same conditions, are as frequently apterous as alate. In 1918, I found that in mixed broods of *M. ribis*, the earlier born individuals were either winged or wingless, while the later born were all winged. This suggested that exhaustion of the parent might influence the form of the young; but this was not confirmed by the experiment of rearing a series of generations, in which the youngest born female of each brood was chosen as the parent of the next(4).

It may also be pointed out that in most species, the last individuals of the whole cycle, the oviparous females, appear just before the leaves fall, and are invariably apterous. It is true that the males in many species are alate, but in the genus *Aphis* they are usually wingless, and in other genera this sex is often dimorphic, winged and wingless forms appearing on the same plant.

Thus the factors controlling the production of winged forms in the Aphidini cannot be considered as determined yet, and may even prove to be in part cyclical.

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# PRELIMINARY OBSERVATIONS ON THE HABITS OF *OSCINELLA FRIT*, LINN.<sup>1</sup>

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(With 1 Text-figure and 2 Charts.)

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## INTRODUCTORY REMARKS.

IN his summary of our knowledge of the frit-fly, Collin (8) indicates that elucidation of the bionomics of the fly in England is very necessary. Most of the data published in recent years are Russian in origin, and probably not applicable to this country.

It was considered advisable to ascertain the relationship between the fly and its environment, therefore the following observations were made in 1919-20 with the view of obtaining evidence as to (a) the prevalence of the fly in the field in the different seasons, and (b) the host plants additional or alternative to cereals.

Observations on prevalence in the field must be obtained in different localities, over several years and correlated with meteorological conditions, for the periods of maximum prevalence to be fixed within the limits induced by seasonal variations. The fixation of these periods will be of importance if control through partial immunity is sought.

<sup>1</sup> A grant in aid of publication has been received for this communication.

The breeding cages used were all normal with such slight modifications as were required.

I am indebted to the Professor of Forestry for the provision of a laboratory, to Professor Somerville for permission to use apparatus and the part provision of an insectary, and to Mr J. E. Collin for freely placing his knowledge of the frit-fly problem at my disposal.

#### A. THE PREVALENCE OF THE ADULT FLY IN THE FIELD DURING THE YEAR.

Various authors in England have noted that the flies swarmed in certain months or on certain days—Westwood (28) in July, Ormerod (21) on July 9th, 1888, Theobald (25) in August—while Collin (8) records that "all stages are easily obtained between May and September." Again, MacDougall (18) states that between June 21st and Sept. 29th he collected the fly on many occasions.

A general deduction from the meagre evidence available would be that the fly is nearly always present in the field in the warm season, but that it becomes very much more abundant both when the oat is in ear and when the grain is ripe.

To test the accuracy of this view, a regular series of field observations, to determine the number of flies present on the crop throughout the growing season, was made in 1919 and 1920. In conjunction with these observations, controlled breeding experiments were conducted, to check the field data.

#### METHOD OF PROCEDURE.

By the courtesy of the Professor of Rural Economy, the observations were made on the University Farm, Sandford-on-Thames. To eliminate, as far as possible, any large influx of flies released by disturbance of other cereal crops, the field selected was one surrounded by meadowland, the nearest cereal crop being a quarter of a mile distant. No information is available as to the normal extent of grass infestation nor as to the migratory powers of the adult fly.

The plan (Fig. 1) indicates the relative areas and positions of the crops grown in this field in 1919-20 and also the position (A) where sweeping operations were conducted<sup>1</sup>.

<sup>1</sup> Observations of the Food Production Department in June, 1919, showed that, in this plot, 37.4 per cent. of the plants were badly attacked, 45.6 per cent. were attacked but sending up ears, while only 17 per cent. were not attacked (*in litt.*).

The flies appeared to frequent the ears, in largest numbers, during calm weather, hence the material was collected about 4 p.m., when generally the wind has least velocity.

The sweepings were made with a 12 ins. diameter net, similar to



Fig. 1. Field of 41 acres in which sweeping was conducted showing crops carried in 1919-20. Relative areas to scale. Spring oats in 1919 variety "Abundance," in 1920 "Excelsior."

Dates of drilling are prefixed.

A. 2. 5. 19 Spring oats.  
10. 3. 20 " "

B. 28. 3. 19 Spring oats.  
10. 3. 20 " "

C. 31. 3. 19 Spring oats.  
15. 5. 19 Rye grass and clover.

D. 30. 10. 18 Winter oats.  
11. 10. 19 Winter oats.

E. 1919 Roots.  
1920 Winter wheat.  
20. 5. 20 Rye grass and clover.

F. 1919 Roots.  
4. 3. 20 Spring oats.

G. 15. 11. 18 Winter oats.  
1920 Roots.

H. Lucerne and grass.

a marine towing-net, the terminal glass tube greatly facilitating the killing and transference of the material collected. Fifty semi-circular sweeps were made, as far as possible of equal value, over the tops of the oat plants, working up the centre of plot and keeping to the same line on each occasion. When weather conditions permitted, collections were

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made on alternate days. To avoid errors in identification<sup>1</sup> the frit material was separated under a binocular microscope.

DATA OBTAINED BY SWEEPING.

The actual figures obtained as a result of sweeping are set out in Tables I and II respectively, as they record the presence of the fly in the field throughout the year except for the winter period October 20th to April 27th, and it is very probable that more diligent search would shorten this period by a week or two.

Table I (1919).

In "Remarks" column, D=sun obscured.

S=sun not obscured.

Number=velocity of wind in miles per hour.

| Date   | No. of flies collected |           |           | Remarks | Date    | No. of flies collected |           |           | Remarks                                     |
|--------|------------------------|-----------|-----------|---------|---------|------------------------|-----------|-----------|---------------------------------------------|
|        | at A                   | at B      | at C      |         |         | at A                   | at B      | at C      |                                             |
| July 5 | 144                    | 157       | 112       | D 11-0  | Aug. 11 | 345                    | Not taken | Not taken | S 2-2                                       |
| 8      | 41                     | 50        | 29        | S 3-6   | 13      | 231                    | "         | "         | S 7-3                                       |
| 11     | 308                    | 223       | 161       | S 7-3   | 15      | 685                    | "         | "         | S 6-6                                       |
| 13     | 78                     | 10        | 34        | D 13-2  | 17      | 502                    | "         | "         | D 8-8                                       |
| 15     | 145                    | 105       | 77        | S 10-2  | 20      | 1437                   | "         | "         | S 7-3                                       |
| 17     | 1110                   | 364       | 135       | S 4-4   | 22      | 22                     | "         | "         | D 13-9                                      |
| 21     | 168                    | 98        | Not taken | D 8-1   | 24      | 541                    | "         | "         | S 5-1                                       |
| 23     | 150                    | 67        | "         | D 14-7  | 26      | 56                     | "         | "         | S 23-5                                      |
| 25     | 453                    | 361       | "         | D 4-4   | 28      | Nil                    | "         | "         | D 16-9                                      |
| 27     | 461                    | 483       | 155       | D 0-7   | 31      | 23                     | "         | "         | S 8-8                                       |
| 29     | 472                    | 468       | Not taken | D 2-9   | Sept. 1 | Crop cut               |           |           |                                             |
| 31     | 127                    | 93        | "         | D 10-3  | 2       | 14                     |           |           |                                             |
| Aug. 2 | 43                     | 17        | "         | D 9-5   | 9       | 23                     |           |           |                                             |
| 5      | 216                    | 268       | 114       | S 8-1   | 19      | 11                     |           |           |                                             |
| 7      | 306                    | Not taken | Not taken | S 5-1   | 30      | 26                     |           |           | From grass headlands, procedure as for oats |
| 9      | 161                    | "         | "         | S 5-9   | Oct. 7  | 15                     |           |           |                                             |
|        |                        |           |           |         | 13      | 4                      |           |           |                                             |
|        |                        |           |           |         | 19      | 1                      |           |           |                                             |

After Oct. 19th, no captures in field.

Sweepings on B and C were discontinued after August 5th as the figures obtained up to that date were confirmatory to those shown under A.

The abundance of the flies on July 17th and August 20th, after rainy periods, should be noted.

<sup>1</sup> Mr J. E. Collin has informed me (*in litt.*) that he is convinced *O. frit* is the only species attacking oats in England.

Only occasionally was *O. pusilla* Meig. observed in the material collected (which included approximately 12,000 specimens of the frit-fly) and then never in large numbers, nor was this species ever reared from puparia collected from oats in the field. On the other hand *O. pusilla* was bred from barley grains, collected at Garsington, Oxon., the flies emerging on 17. 8. 20. Mr Collin, in confirming the identification, stated that, as far as he was aware, this is the first record of this species attacking cereals in England. Again, this species was bred from field specimens of *Hordeum murinum*, two flies emerging on 13. 10. 20.

Table II (1920).

In "Remarks" column, D=sun obscured.

S=sun not obscured.

Number=velocity of wind in miles per hour.

| Date     | No. of flies<br>collected at A | Remarks | Date    | No. of flies<br>collected at A | Remarks |
|----------|--------------------------------|---------|---------|--------------------------------|---------|
| April 28 | 1                              | 16.2    | June 18 | 32                             | D 8.8   |
| 30       | Nil                            | 11.0    | 21      | 168                            | S 9.5   |
| May 2    | 11                             | 16.2    | 23      | 375                            | S 8.1   |
| 4        | 5                              | 11.0    | 26      | 222                            | D 7.3   |
| 6        | 1                              | 17.6    | 28      | 205                            | D 11.0  |
| 8        | 19                             | 11.7    | 30      | 298                            | S 11.7  |
| 9        | 48                             | S 4.4   | July 2  | 76                             | D 14.7  |
| 10       | 56                             | S 6.6   | 3-8     | Too wet for sweeping           |         |
| 11       | 26                             | D 8.8   | 9       | 38                             | S 13.9  |
| 13       | 37                             | S 13.2  | 12      | 66                             | D 14.7  |
| 15       | 12                             | D 11.0  | 14      | 80                             | D 10.2  |
| 19       | 42                             | D 11.0  | 16      | 293                            | D 11.0  |
| 22       | 79                             | S 8.8   | 19      | 469                            | D 12.4  |
| 24       | 18                             | S 8.8   | 22      | 18                             | D 16.9  |
| 27       | 28                             | D 8.1   | 24      | 38                             | S 10.2  |
| 29       | 21                             | D 14.7  | 26      | 52                             | S 9.5   |
| 31       | 7                              | D 11.0  | 27      | 31                             | S 13.2  |
|          |                                |         | 29      | 102                            | S 4.4   |
| June 2   | 75                             | S 9.5   | 31      | 128                            | S 8.8   |
| 4        | 42                             | D 11.7  | Aug. 3  | 8                              | D 13.2  |
| 6        | 50                             | D 5.9   | 5       | 7                              | D 13.2  |
| 8        | 30                             | S 8.1   | 7       | 31                             | S 7.2   |
| 11       | 41                             | S 8.1   | 9       | 4                              | 13.9    |
| 13       | 33                             | D 6.6   | 12      | 99                             | 4.4     |
| 15       | 75                             | S 4.4   |         | Crop cut                       |         |

## OBSERVATIONS IN THE INSECTARY.

Controlled breeding experiments, with field material, were conducted to ascertain the relationship between the periods of high prevalence in the field and the production of successive broods or generations.

The environmental conditions inside the cages were artificial, excessive moisture and close confinement being unfavourable factors whilst protection from direct sunlight and the presence of a plentiful food supply were favourable factors. Therefore the period between the dates of the infection and the emergence of the flies of the next generation may be only approximate to the natural period.

*Method.*

Flies were collected in the field on 15. 5. 20 and used to infect various cereals which had been grown under protective covering. In each case

a few plants were potted out, covered with the ordinary chimney cage and kept, for the experimental period, in the insectary. Abundant moisture, and food in the form of cane-sugar, were supplied.

The sexes were easily identified under the binocular microscope, the flies being tubed separately and, when necessary, rendered temporarily immobile by means of a wisp of cotton-wool. The parent flies were undoubtedly of various ages and probably some of the females had completed oviposition.

The data obtained from these breeding experiments are detailed in Synopsis I.

#### SYNOPSIS I.

Figures in columns 4-8 refer to the number of days after date of infection (15. 5. 20).

| Cereal                    | Height of plant in inches | Parents           |    | Parents removed | The first sign of attack                                      | Emergence of                 |          | Av. emergence No. of flies in brackets |
|---------------------------|---------------------------|-------------------|----|-----------------|---------------------------------------------------------------|------------------------------|----------|----------------------------------------|
|                           |                           | ♂                 | ♀  |                 |                                                               | first fly                    | last fly |                                        |
| Barley . .                | 6                         | 10                | 10 | 31              | 14                                                            | —                            | —        | —                                      |
| Spring wheat              | 3                         | 10                | 10 | 31              | 12                                                            | 46                           | 53       | 50.4 (5)                               |
| Spring oat .              | 8                         | 10                | 10 | 31              | 15                                                            | 45                           | 55       | 50 (2)                                 |
| Spring oat .              | 8                         | 7                 | 8  | 33              | —                                                             | 46                           | 63       | 49.2 (4)                               |
| Winter wheat              | 12                        | 7                 | 8  |                 | Negative                                                      |                              |          |                                        |
| Winter oat .              | 12                        | 7                 | 8  | 20              | 3 eggs, larvae failed to emerge                               |                              |          |                                        |
| Maize . .                 | 5                         | 5                 | 5  | 28              | 7 eggs on dead sheaths, 4 larvae emerged but failed to mature |                              |          |                                        |
| Spring oat <sup>1</sup> . | 8                         | 10                | 10 | 4               | 11                                                            | 41                           | 45       | 43 (2)                                 |
|                           |                           | (Coll. 24. 5. 20) |    |                 |                                                               | Omitted from general average |          |                                        |

To avoid confusion between individuals of the consecutive generations, the parent flies were removed from the cages before the emergence

<sup>1</sup> Examination of the cages after emergence had ceased showed that larvae from very young tillers pupated either in the tiller, in the sheath, or in the soil (one case). Larvae in main shoots pupated in the gallery near the top. This is in accordance with field observations, pupation in the soil being rare. In the first cage of spring oats, six puparia were found (flies dead in four) in four main shoots, only one of which showed normal signs of attack. The blades were only partially cut and remained green.

In the case of the barley two puparia (flies dead) were found on examination after 67 days (from date of infection). One larva bored through the stem of an oat plant and pupated on the external surface immediately below the exit hole after 30 days, the fly emerging after 45 days.

A pupal period averaging 16.5 days was noted in the case of larvae in oat stems brought in from the field, potted and caged. In four cases puparia were exposed and the following data obtained:

|               |          |           |         |           |                    |
|---------------|----------|-----------|---------|-----------|--------------------|
| Larva pupated | 8. 6. 20 | ♀         | emerged | 25. 6. 20 | i.e. after 17 days |
| "             | "        | 9. 6. 20  | ♂       | "         | 27. 6. 20 " 18 "   |
| "             | "        | 13. 6. 20 | ♀       | "         | 28. 6. 20 " 15 "   |
| "             | "        | 13. 6. 20 | ♂       | "         | 29. 6. 20 " 16 "   |

*O. frit* was bred from Browich wheat grains, flies emerging on 12. 8. 20. Samples of eleven other varieties failed to yield the fly.

of their progeny. These flies were caged with new host plants to see whether they were capable of producing another brood. In addition, the first progeny were also caged with separate host plants in order that the period between the emergence of Generations I and II<sup>1</sup> might be determined.

The data obtained from these cages are detailed below.

Thirty of the parents were removed alive 28 to 31 days after the date of the first infection (15. 5. 20) and used to infect oat plants grown under a protective covering. In the three experiments the flies were provided with sugar and water.

(a) On the 31st day sixteen flies were placed on the ears of spring oat plants, which flowered on the 32nd day. Copulation between one pair was observed on the 43rd day, eggs being deposited in the glumes on the 45th day. Twelve living parent flies were removed on the 45th day.

*Result:* no flies emerged and probably the larvae failed to mature owing to lack of nutriment.

(b) On the 32nd day, fourteen flies were placed on spring oat plants not in ear. Copulation was observed between one pair on the 38th day and five living parent flies were removed on the 45th day.

*Result:* the first and last flies emerged on the 69th and 81st days respectively, and the average period was 78.7 days (seven flies).

(c) The eleven flies which were bred out about the 50th day were placed on the ears of spring oat, being removed on the 65th day.

*Result:* the first and last flies emerged on the 82nd and 85th days respectively, the average period being 83.3 days (three males), *i.e.* 33.4 days after the emergence of their parents.

The result of all these experiments is that, from parent flies of Generation III, adult flies of Generation I were obtained after approximately 50 days, and from the same parent flies of Generation III a second series of adult flies of Generation I was obtained in 78.7 days. Also nine of the original parents lived until the 50th day and one until the 59th day, time enough to have produced yet a third brood under favourable circumstances.

<sup>1</sup> In this paper, for convenience of reference only, the generations at present recognised are numbered. I am convinced that further experiment will show that more than three generations may be produced in the field. Generation I refers to the individuals which pass through the stages, egg to adult in spring, Generation II to the individuals passing through the same stages in the summer and Generation III to the individuals which hibernate in the immature stages. In the following spring these individuals produce Generation I.

Again the first brood (Generation I) gave rise to adult flies of Generation II after 33.4 days.  $C'-D$ ,  $C'-E$  and  $D-F$  marked on Chart II, p. 115, represent these periods respectively.

Oviposition probably took place soon after 15. 5. 20 and again soon after 17. 6. 20 (the parents being in constant association with plants) as the issue are grouped over two periods, namely, after 50 days (with a maximum of 63 days) and 79 days (with a minimum of 69 days). Therefore the average interval extends to 29 days, which is most probably the interval between the production of separate broods of flies of Generation I. The interval between the emergence of the last fly of the first group and the first fly of the second group is 6 days.

#### DISCUSSION OF DATA.

##### *Significance of Prevalence.*

The term "prevalence" is used to denote the presence of flies in the field without distinction of brood or generation. Prevalence and emergence are not synonymous terms, as, for a particular brood or generation, the period of prevalence will exceed the period of emergence, by the longevity.

In Charts I and II, pp. 114, 115, will be found smoothed<sup>1</sup> curves representing the prevalence of frit-fly in the latter part of 1919 and in 1920 respectively. Rainfall, maximum shade temperature and minimum grass temperature, also smoothed, are included<sup>2</sup>.

The maximum temperature<sup>3</sup> in the sun has a direct influence on the apparent prevalence at different hours of the day, as determined by sweeping, but a much less effect than the more even maximum shade temperature on the prevalence from day to day. Usually frit-flies are

<sup>1</sup> The curves have been smoothed, as exemplified here. Taking, for example, the readings for June 2-8, 1920—the adopted means for June 4 and June 6 are the means of readings for the days 2-4-6 and 4-6-8 respectively.

The corresponding means of meteorological data were calculated from the daily readings of the periods 2-6 and 4-8 respectively, because the weather conditions over the whole period would control the total emergence and therefore the prevalence.

<sup>2</sup> I have to thank Dr Rambaut (the Radcliffe Observer) for these figures. This station is separated from the farm by  $3\frac{1}{2}$  miles, both having about the same altitude. The error in the farm observations no doubt greatly exceeds the error introduced by utilising the meteorological records of this Station. Self-recording instruments were not available for use on the farm.

<sup>3</sup> Graham-Smith (14) showed that curves for common Muscid flies, caught in traps in the open air, corresponded most clearly to the curve for the maximum temperature in the sun. In this case, however, the number of flies trapped was proportional to the activity of the fly and was not necessarily a measure of the prevalence of the flies at any one time.

more active in warm, sunny and calm weather, but under adverse conditions they seek shelter in the areas protected by the plant foliage, in which areas their activity would presumably be influenced only by the maximum shade temperature. When sweepings are taken on successive days at a definite hour, it is considered that variations in the records, due to fluctuations in the maximum temperatures in the sun, are to a great extent eliminated, especially when the results are meaned as explained above.

Charts I and II show a general prevalence of the fly in the field throughout the warm season together with certain periods of high prevalence<sup>1</sup>. The intervening minima will be real if it can be shown that the absence of flies from the field is not falsely represented owing to the weather conditions being unfavourable for collection.

Considering the minima in succession, first on Chart I and then on Chart II, it will be seen that the weather conditions in the first week of August, 1919, were favourable for collection, the velocity of the wind being about normal (*vide* Table I), rain absent and temperature on the up-grade. One cannot determine the reality of the first two minima in Chart II, as the crops, at this time of the year, show very little growth and collection by sweeping may not be giving very accurate data. About June 8th, however, conditions were good although few flies were caught. On July 7th to 12th conditions were bad, the weather generally being wet, cold, and windy. Yet on July 14th, under conditions much the same as those of July 16th, only one-third of the number of flies was collected. The weather on July 27th is recorded as being sunny and calm, yet the number of flies caught was distinctly low and a similar result was obtained under similar conditions on August 7th. Immediately afterwards, the prevalence curve tends to rise but at this time the crop was cut.

Thus the minima appear to be caused by a real absence of the flies from the field and therefore the frit-fly has certain periods of high prevalence.

#### INTERPRETATION OF THE PREVALENCE CURVES.

The tendency in the past has been to conclude that periods of high prevalence coincided with the appearance of successive generations. The abundance of flies has been roughly correlated with the condition of the crop and at the same time associated with the three generations at present recognised.

<sup>1</sup> As the oat crop is nearly always removed before the life-history for the year is completed, one or more maxima will not appear on the Charts.

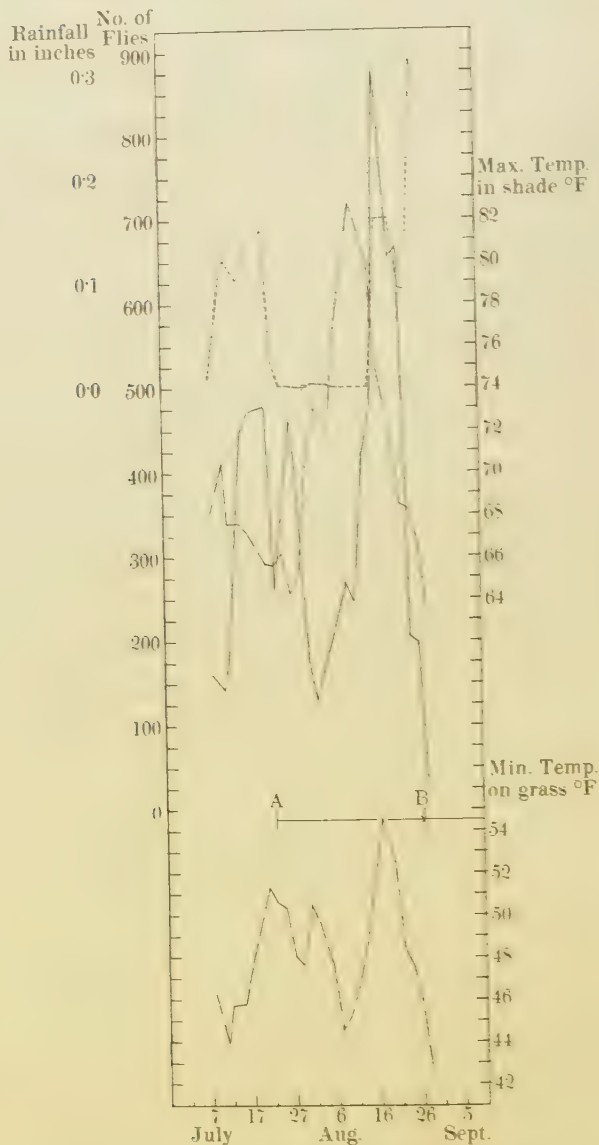


CHART I. Dotted line = rainfall; upper broken line = maximum temperature in the shade; lower broken line = minimum temperature on the grass; unbroken line = prevalence curve. 1919.

A—B = average interval in days required for the production of a new generation.

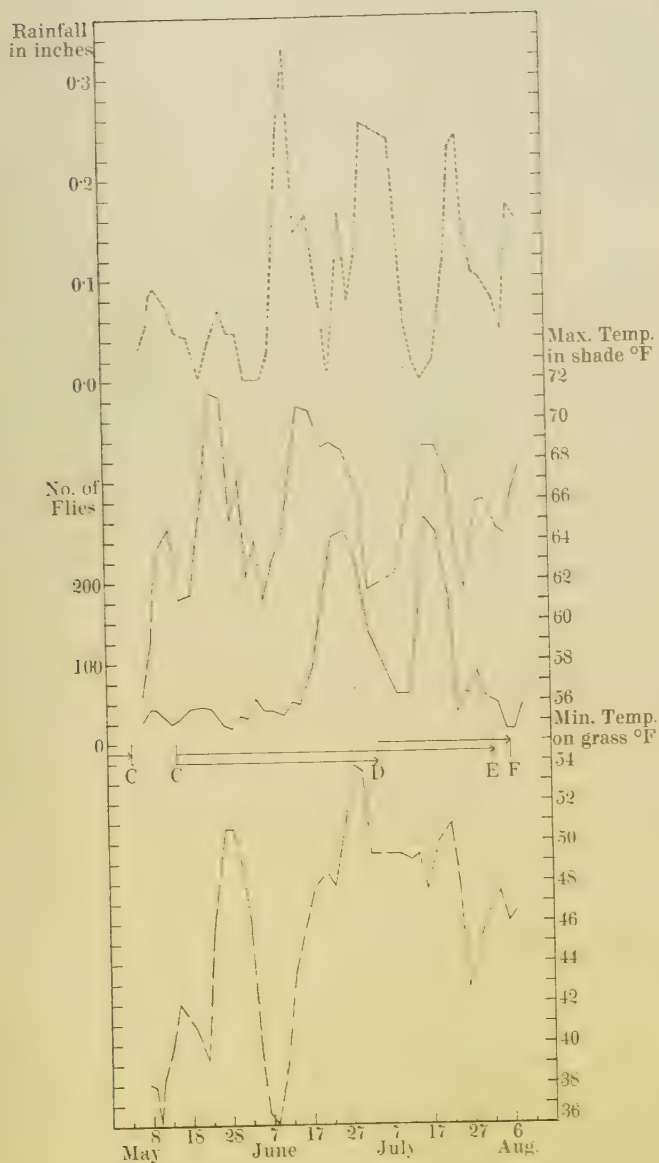


CHART II. See Chart I for key to curves. 1920.

*C* = time of appearance of flies bred in grasses over the winter.

*C'*—*D* and *C'*—*E* = average intervals in days required for the production of first and second brood flies from parent flies at *C'*.

*D*—*F* = average period in days required for the production of flies from the above first brood flies.

The environmental conditions, however, may exercise a very decided influence on the prevalence, most probably masking the effect of the emergence of broods or generations.

For this reason the curves are considered below under two headings, indicating the relationship between (a) high prevalence and brood production, and (b) high prevalence and environment.

(a) *High Prevalence and Brood Production.*

It has been assumed in England that the generation which breeds on grasses over the winter gives rise to another generation which attacks oat stems and tillers, and this, in turn, to a third generation which attacks oat grain.

Quite recently, it has been suggested by Roebuck (1921), that the life-history is more in accordance with continental observations, which, in general, indicate the occurrence of more than three generations. From field evidence, collected over a period of five years, Roebuck concluded that a "brood" is normally interpolated between Generations I and II as generally recognised at present. It is not clear what is meant exactly by the term "brood," in this paper, but there is no doubt that the presence of only two overlapping broods or generations on the oat crop is considered to be very doubtful<sup>1</sup>.

When these prevalence curves in Charts I and II are considered in conjunction with the experimental evidence detailed above, it becomes very difficult to believe that the minima of the curves are, in general, closely associated with the imminence of broods or generations. As indicated on p. 112, and marked on Chart II, parents at *C'* gave rise to a first brood at *D* which in turn gave a first brood at *F*; also the parents at *C'* gave rise to a second brood at *E*. Although experimentally the

<sup>1</sup> This conclusion is drawn from the following observations (*vide Ann. App. Biol.* VII, p. 181):

| Site of pupa          | Earliest gathered pupa | Period of maximum emergence of flies |
|-----------------------|------------------------|--------------------------------------|
| Grass stems . . .     | March 25               | May, 1st week                        |
| Base of oat tillers . | May 21                 | June, middle                         |
| Panicle inside leaf   | June 24                | July, 3rd week                       |
| Oat grains . . .      | July 31                | September, 1st week                  |

Aldrich (1) summarises the life-history in North America as consisting of the winter generation and "following the emergence of this brood as adults in the spring, there are four summer broods." But he does not make it clear whether or no he considers these broods to be equivalent to successive generations. In his tabulated results, he only records that each cage was started "using flies that had emerged a few days before," without stating whether any of the parents were actually bred personally.

It is probable therefore that his figures have reference to broods only and not generations.

broods at *E* and *F* failed to reproduce themselves, in the field they would undoubtedly do so at this time of year. In 1919, when breeding flies on grasses (p. 120), it was found (1) that parent flies at *A* gave rise to flies at *B*, and (2) that either the flies at *A* or *B* gave rise to another series of flies in the middle of September. In the field flies would be constantly emerging.

Under natural conditions moisture is abundant, a sufficiency of food always available and suitable breeding places are provided in succession by the growth of the host plant, namely first the tillers, then the young panicles, and lastly the young grain. In addition wild grasses are always present and a few common species can be utilised for breeding purposes. For example, flies bred from oat stems at *A* would normally have oviposited on the oat panicles, but when compelled, reproduced themselves on the young stems and tillers of grasses<sup>1</sup> and similarly the flies at *D* bred on oat tillers in place of oat grain. All that seems to be required by the larvae is young and rapidly growing tissue and neither the position of the tissue on the plant nor the species of plant (within small limits) is important. Therefore there is no reason to assume that reproduction would be checked by lack of food or host plants.

The irregularity of the emergence obtained experimentally would be highly magnified in natural conditions and the various maxima which appear on the charts will be composed of flies of different broods and generations, the complexity becoming very great towards the end of the season. Although it is fairly clear that the first generation becomes abundant in the first week of June, after this time it has been found impossible to separate the different broods and generations on the charts or to associate them with the high prevalence periods. As the flies are not restricted to particular breeding places, the proportions of the broods and generations at any one period becomes a matter of minimal importance.

It would seem from the experimental data obtained in 1919-20 that three or even four distinct generations may be produced in a favourable season.

(b) *High Prevalence and Environment.*

Many factors influence the emergence of an insect breeding under normal conditions in the field. With a phytophagous insect, growth of host plant, rainfall and temperature are probably the more important

<sup>1</sup> *Vide* Section B.

factors. Humidity will have but little influence in the case of the frit-fly as the immature stages are passed in very close proximity to the plant surface, where the humidity is high.

It was expected that the correlation between prevalence and meteorological conditions would be more apparent than is indicated on the charts. There would appear to be some relation between high prevalence and high temperature, and emergence seems to follow periods of rainfall. It is obvious however that insufficient data have been obtained and more are being collected in an endeavour to settle the relationship.

Graham-Smith (13) found that common Muscid flies were very sensitive to meteorological changes, extremes in either direction killing off the flies in large numbers. It has been pointed out above that on certain days, namely July 14th, July 27th and August 7th the flies appeared to be practically absent from the field, although conditions for collection were not markedly unfavourable. It will be shown that, under control, the flies may live for as long a period as 66 days (p. 124), both in spring and summer, an interval much in excess of that between any two maxima shown by the curves. The only conclusion is that longevity in the field must be greatly curtailed by the action of undetermined environmental factors.

The influence of relative preference and parasitism, on the prevalence of the fly on any one crop, has yet to be determined.

#### ADDENDUM.

The greater abundance of the fly in 1919 is very striking. In the period July 5th to October 19th, 8319 flies were collected as against 3597 flies between April 28th and August 12th, 1920 (3657 flies being collected in July 1919, but only 1391 in July 1920, in an equal number of sweeps).

The results of comparative sweeping on plots A, B and C (*vide* Table I) seem to indicate that the fly normally remains close to the locality of its emergence. This view is supported by the following figures showing the percentages of unattacked plants on the various plots in 1919 and 1920.

|         |      |               |      |
|---------|------|---------------|------|
| 1919: A | 17.0 | 1920: A and B | 30.0 |
| B       | 71.3 | F             | 49.2 |
| C       | 75.0 |               |      |

B and C (1919) were drilled on March 28th and A (1919) on May 2nd with the variety "Abundance."

A, B and F (1920) were drilled with the variety "Excelsior" on Mar. 4th to 10th.

In 1919, therefore, crop A presented host plants more suitable for oviposition at the time when the flies were abundant, and this crop was most heavily attacked. In 1920 when the seeds were drilled in at about the same times, the attack was more severe on the land which had been heavily infested the previous year, even though there was no apparent difference in the condition of the crops.

#### B. HOST PLANTS AMONG WILD AND PASTURE GRASSES.

It has been assumed that grasses are the host plants of the frit-fly during the winter, because frit-like larvae have been discovered in various grasses at this time of year.

Ormerod (21) records, from Continental literature, that "the larvae are found in meadow grasses in summer." The normal utilisation of grasses, as alternative hosts, was evidently not realised. In the previous year it was recommended that oats should be left out of the rotation for a while, in badly infested districts, "as the surest method of all to prevent a continuance of attack." Ritzema Bos (23) records that the larvae live, according to the time of year, in wild or pasture grasses, and Carpenter (6) evidently quotes from similar records.

Edmunds (12) states that he found the larvae in rye grass and also in *Avena flavescens* and *Arrhenatherum avenaceum*, but he does not appear to have bred them through to the adult stage, therefore he may have been dealing with another species of *Oscinella*.

Baranov (3) points out that the larvae hibernate in wild grasses (without mentioning species), and also that the spring generation oviposits on *Phleum pratense*, *Alopecurus pratensis*, *Lolium perenne*, *Triticum cristatum*, *Festuca pratensis*, *Avena flavescens* and *Poa pratensis*.

Criddle (9), referring to *O. coxendix* Fitch, reports, from Manitoba, a severe infestation of cereals on grasslands ploughed in late autumn or spring. But on permanent pastures in England, Cameron (4, 5) and Morris (19) did not find frit-fly. Schøyen (24) noted that the first generation deposited eggs on the leaves of young plants of quick grass and timothy grass. Aldrich (1) in N. America bred flies from larvae which had wintered in *Phleum pratense* and *Festuca elatior*.

Roebuck (1921)<sup>1</sup> records the emergence of flies from *Arrhenatherum* in the first week of May. The possibility of the fly breeding in such common alternative hosts as wild and pasture grasses has therefore

<sup>1</sup> *Ann. App. Biol.* VII, pp. 178-182.

been realised, but very little experimental breeding has been recorded in proof thereof and no attempt has been made to estimate the relative preference for different grasses at different periods of the year.

#### *Method.*

Breeding the flies from infected grasses brought in from the field gave uncertain results, since it was almost impossible to obtain pure clumps, except in very few cases, *e.g.* *Lolium* spp. and *Alopecurus myosuroides*. Sowing seed in small patches in the field was also ineffective. Pot experiments gave positive results (detailed in Synopsis II) with some host plants but without regularity. Negative results, therefore, had very little value.

Samples of common wild and pasture grass seeds were collected and sown separately in 9-inch pots, netted and kept for convenience of observation, in an unheated greenhouse<sup>1</sup>, with the lights always fully open.

Flies were reared from field plants, sexed under the binocular microscope, and introduced into the cages. The flies on emergence were easy to observe, as on disturbance they congregated at the tops of the cages.

Two series of plants were infected, one in July and the other in August, 1919<sup>2</sup>.

There is no evidence that the flies reproduce themselves without previously securing food supplies, and the longevity experiments (p. 123) indicate that food would probably be sought<sup>3</sup>. If food is essential, the adults in these experiments obtained sufficient from these particular grasses to enable them to reproduce, but probably insufficient to enable them to live a normal period. In 1919, in the cage of *L. italicum*, the last fly died on October 14th and in the cage of *L. perenne*, on October 11th (*vide* Table I for field record).

The parent flies used in these experiments were not more than 5 days old and the majority less.

<sup>1</sup> An insectary was not available at this date.

<sup>2</sup> Negative results were obtained with the following grasses in both series of experiments: *Alopecurus pratensis*, *Arrhenatherum avenaceum* var. *bulbosum*, *Avena flavescens*, *Bromus sterilis*, *Holcus lanatus*, *Hordeum murinum*, *Phleum pratense*, *Poa pratensis*. Six other grasses also gave negative results, but here growth was not considered normal. Further experiments are being conducted this season with all these host plants in large breeding cages under more natural conditions.

<sup>3</sup> On April 4th, 1920, many flies were observed frequenting apple blossom on trees near the oat crop, and in May and June, on the flowers of *Veronica hederifolia* in the field, apparently feeding. Knuth<sup>(15)</sup> records *O. frit* as visiting *Potentilla sylvatica*, *Daucus carota*, *Matricaria inodora* and *Mentha aquatica*.

SYNOPSIS II.

*Series I.*

Infection light. Seeds sown 11. 7. 19. Plants infected on 23. 7. 19 when plants 3-5 inches in height. No food supplied. Experiments continued through winter of 1919, no flies being removed from cages. Periods reckoned in days after date of infection.

| Host plant                     | No. of flies used in infection |   | No. of days between infection and death of last parent | Emergence                                   |                      | Average periods                   |
|--------------------------------|--------------------------------|---|--------------------------------------------------------|---------------------------------------------|----------------------|-----------------------------------|
|                                | ♂                              | ♀ |                                                        | 1919                                        | 1920                 |                                   |
| <i>Poa annua</i>               | 7                              | 9 | 14                                                     | 3 flies between 34-47 days                  | —                    | 39 days                           |
| <i>Festuca pratensis</i>       | 5                              | 7 | 13                                                     | 5 flies 31-37 days                          | —                    | 33 days                           |
| <i>Lolium italicum</i>         | 7                              | 8 | 18                                                     | 13 flies 27-40 days;<br>11 flies 61-76 days | 2 flies on 28. 4. 20 | 1st emergence, 1919,<br>32.4 days |
| <i>Lolium perenne</i>          | 6                              | 8 | 17                                                     | 25 flies 31-47 days;<br>9 flies 62-64 days  | 1 fly on 12. 5. 20   | 1st emergence, 1919,<br>41.4 days |
| <i>Arrhenatherum avenaceum</i> | 5                              | 5 | 13                                                     | 5 flies 29-34 days;<br>1 fly after 63 days  | —                    | 2nd emergence, 1919,<br>62.3 days |
|                                |                                |   |                                                        |                                             | —                    | 1st emergence, 1919,<br>31.8 days |
|                                |                                |   |                                                        |                                             | —                    | 2nd emergence, 1919,<br>63 days   |

*Control experiment for Series I.*

30. 7. 19. ♂ and ♀ (emerged from puparia from oat grains) were placed on clean oat panicles and provided with moisture only. Parents dead after 5 days.

*Result:* The first and last flies emerged after 27 and 35 days respectively, the average period being 31 days (five flies, two ♂ and three ♀). (By an oversight these flies were not supplied with moisture and died without reproducing.)

*Series II.*

Infection heavy, no food supplied.

| Host plant                     | No. of flies used in infection (bred from infested grain) | No. of days between infection and death of last parent | Emergence reckoned in days after infection |                                           | Remarks                                                                    |
|--------------------------------|-----------------------------------------------------------|--------------------------------------------------------|--------------------------------------------|-------------------------------------------|----------------------------------------------------------------------------|
|                                |                                                           |                                                        | 1919                                       | 1920                                      |                                                                            |
| <i>Alopecurus agrestis</i>     | 50                                                        | 12                                                     | —                                          | 6 flies between 252-253 days <sup>1</sup> | Sown 15. 7. 19.<br>Infected 21. 8. 19.<br>1st sign of attack after 22 days |
| <i>Hordeum pratense</i>        | 50                                                        | 15                                                     | —                                          | 1 fly after 251 days                      | Sown 28. 7. 19.<br>Infected 23. 8. 19.<br>1st sign of attack after 27 days |
| <i>Arrhenatherum avenaceum</i> | 50                                                        | 14                                                     | —                                          | 1 fly after 263 days                      | Sown 28. 7. 19.<br>Infected 19. 8. 19                                      |

<sup>1</sup> These flies failed to reproduce themselves on the same host plants in the summer of 1920.

The results of the experiments of Series I give a mean of 35.5 days, and this is the average period elapsing between the times of emergence of consecutive generations in the summer.

This period is the same whether the fly breeds on grasses or cereals.

The experiments in Series II indicate an average period of 254 days as the time required for the metamorphosis of the winter generation.

The emergence of a second series of flies, after 63 days, in the last three cages (Series I) is of interest. The average period between the times of emergence of the first and second series is only 27.5 days, too short a period for the time of year (September), to enable one to presume an additional generation. On the other hand, taking the three cases, the greatest length of life of an individual of the first series is 47 days and the shortest interval between the death of the last parent and the earliest emergence in the second series is 43 days; thus it would seem to be a case of either deferred oviposition or the production of a second brood.

It has been proved therefore that frit-fly is able to utilise the following grasses as host plants in the summer: *Arrhenatherum avenaceum*, *Festuca pratensis*, *Lolium italicum*, *L. perenne* and *Poa annua*.

In addition flies were reared in the spring of 1920 from the following grasses which had been infected in 1919: *Alopecurus myosuroides* (= *agrestis*), *Arrhenatherum avenaceum*, *Hordeum pratense*, *Lolium italicum* and *Lolium perenne*.

#### ADDENDUM.

The following data indicate the extent of the infestation of two common grasses and also that an absence of the typical sign of attack does not necessarily mean the absence of the pest. No decided preference for volunteer oat plants was apparent.

*Lolium italicum* and volunteer oat plants from plot C (Fig. 1) were collected on 11. 3. 20. Plants were picked at random about every 3 feet, to the number of about 150 for each species, and carefully examined. Control plants produced frit-fly in the first half of May.

|                        | No. of<br>plants | % larvae<br>found | Signs of<br>boring-larvae<br>absent | % of larvae<br>in stems<br>showing no<br>sign of<br>attack | % plants showing<br>typical sign of<br>attack but no<br>trace of frit<br>boring |
|------------------------|------------------|-------------------|-------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------------------|
| <i>Lolium italicum</i> | 170              | 8.2               | Nil                                 | 43                                                         | 14.8                                                                            |
| Volunteer oat          | 149              | 10.8              | „                                   | 29                                                         | 9.2                                                                             |

The plants referred to in the last column showed the dead central shoot typical of frit attack, and cursory examination in the field would have led one to suppose that the frit-fly was the cause of the damage.

Actually there was no sign of a central gallery such as is drilled by the frit larva, but only a small lateral cavity, low down on the stem, probably due to the attack of the larva of a *Tipula* sp.

Later in the season (8. 6. 20) *Alopecurus myosuroides* (= *agrestis*) on plots A and B (Fig. 1) was found to be infested to the extent of 89 per cent. (137 plants), the infestation of the oat crop at this time being only 70 per cent. The identification of flies bred from this grass was confirmed by Mr J. E. Collin.

Examination of the winter oats on plot C (Fig. 1) on 23. 3. 20 showed that infection was very light. Nine samples, averaging 55 plants each, were collected at random about every 3 feet and examined by dissection. Only 0.7 per cent. of the plants contained frit-fly larvae and 0.6 per cent. showed signs of boring without containing larvae. On 14. 6. 20, however, larvae were very numerous in the young tillers.

These oats followed a crop of winter oats in 1919.

### C. APPENDIX.

Whilst making the investigations previously described, various notes<sup>1</sup> of economic interest were compiled and are presented under the following headings:

- (1) The longevity of the imago in captivity.
- (2) The value of ploughing as a repressive measure.
- (3) The effect of manurial treatment.
- (4) Parasites.

#### THE LONGEVITY OF THE IMAGO IN CAPTIVITY.

As there appear to be no records of the longevity of the adult flies in England the following data is of interest. Observations were made on flies kept at the same temperatures, with and without food and moisture, in the spring and summer seasons.

It may be pointed out that Continental records vary very considerably (from 1 day to 5 months), but the environments doubtless varied also.

#### *Method.*

The flies were reared separately, in tubes, from puparia collected in the field, either from oat stems or oat grains according to the season,

<sup>1</sup> To comply with the recent decision of the Publications Committee, this paper has been curtailed considerably, notes on the action of the larvae on the host plant, on copulation and oviposition and on the ratio of the sexes in the field having to be omitted.

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the dates of emergence being noted. Individuals emerging on the same days were caged<sup>1</sup> together and sexed after death.

SYNOPSIS III. *Observations in 1920 (Spring).*

All cages kept in the insectary.

| Conditions under which flies were kept                                                                   | Date caught in field <sup>2</sup> | Sex       | Length of life in days                                 |         |                |
|----------------------------------------------------------------------------------------------------------|-----------------------------------|-----------|--------------------------------------------------------|---------|----------------|
|                                                                                                          |                                   |           | Minimum                                                | Maximum | Average period |
| { Food, nil ... ..                                                                                       | 12. 5. 20                         | ♂         | 3                                                      | 5       | 3.5 ( 4 flies) |
| { Moisture, nil ...                                                                                      | 5. 5. 20                          | ♀         | 3                                                      | 8       | 4.2 (32 " )    |
| { Food, nil ... ..                                                                                       | 11. 5. 20                         | ♂         | 4                                                      | 6       | 5 ( 3 " )      |
| { Moisture, abundant                                                                                     | 22. 5. 20                         | ♂         | 3                                                      | 9       | 7.1 (12 " )    |
| {                                                                                                        | 11. 5. 20                         | ♀         | 2                                                      | 7       | 5.1 (15 " )    |
|                                                                                                          | 22. 5. 20                         | ♀         | 4                                                      | 9       | 7 (17 " )      |
| { Food, sugar ... ..                                                                                     | 18. 5. 20                         | ♂         | 6                                                      | 40      | 28.6 (12 " )   |
| { Moisture, abundant                                                                                     |                                   | ♀         | 10                                                     | 62      | 44 (29 " )     |
| Flies used in experiments (Section A, p. 109) constantly associated with growing plants and fed on sugar | 15. 5. 20                         | Not sexed | Out of 111 flies:<br>30 lived until after the 31st day |         |                |
|                                                                                                          |                                   |           | 17                                                     | "       | " 45th "       |
|                                                                                                          |                                   |           | 9                                                      | "       | " 52nd "       |
|                                                                                                          |                                   |           | 1                                                      | "       | " 59th "       |

SYNOPSIS IV. *Observations in 1919 (Summer).*

The last three cages were kept in the shade, 3 feet from ground.

| Conditions under which flies were kept | Date of emergence | Sex | Length of life in days |         |                |
|----------------------------------------|-------------------|-----|------------------------|---------|----------------|
|                                        |                   |     | Minimum                | Maximum | Average period |
| { Shade near ground                    | 20. 8. 19         | ♂   | 5                      | 10      | 7.7 (10 flies) |
| { Food, nil ... ..                     |                   | ♀   | 8                      | 16      | 11.2 ( 4 " )   |
| { Moisture, condensation               |                   |     |                        |         |                |
| { Food, nil ... ..                     | 22. 8. 19         | ♂   | 3                      | 5       | 4.3 ( 3 " )    |
| { Moisture, nil ...                    |                   | ♀   | 5                      | 11      | 5.3 ( 6 " )    |
| { Food, nil ... ..                     | 22. 8. 19         | ♂   | 6                      | 8       | 6.6 ( 5 " )    |
| { Moisture, abundant                   |                   | ♀   | 6                      | 14      | 11.2 ( 5 " )   |
| { Food, sugar ... ..                   | 22. 8. 19         | ♂   | 29                     | 66      | 50.8 ( 5 " )   |
| { Moisture, abundant                   |                   | ♀   | 17                     | 66      | 50.0 ( 5 " )   |

<sup>1</sup> The cages were glass cylinders, with muslin covers, standing on several pieces of filter paper, which were placed on a plate. Food was placed in a muslin bag slung inside and the filter paper kept saturated with water. When moisture was withheld, the paper was omitted.

<sup>2</sup> Some evidence as to the probable length of life of the individual early in the year was desired, but winter crops in this district are not heavily infected and time was not available for prolonged searching for puparia among infected grasses. No doubt the average period is low and the maximum period nearer the true period.

The length of life, under similar conditions as to food supply, is the same in summer as in spring. The presence of an abundant water supply only doubles the life of the individual, whereas a plentiful food supply in addition, ensures a life ten times as long. Under adverse conditions the female is more resistant than the male. It has been shown in Section A (p. 111) that reproduction can take place at least 30 days after emergence.

The longevity of the fly in the field is probably very variable and entirely dependent on meteorological conditions. For this reason no approximation to the longevity in the field can be deduced from the prevalence curves shown in Section A.

#### THE VALUE OF PLOUGHING AS A REPRESSIVE MEASURE.

Collin<sup>(8)</sup> remarks that "no definite experiments, beyond those of Krassiltchik and Vitkovsky mentioned under 'Pupae' appear to have been made as to how far the fly can be controlled by being buried under the ground in its earlier stages, especially as to whether the larva can complete its feeding and pupate after the affected plant has been ploughed in."

Among the earlier authors there was some confusion of species and control by ploughing was not advocated, but latterly this measure has been recommended by many, *e.g.* Ormerod<sup>(21)</sup> suggested ploughing "with a skim-coulter attached so as to bury infested plants well down," and Carpenter<sup>(6)</sup> without any apparent justification goes one step further and says "it is advisable to plough a hopelessly lost crop deeply into the soil, as the maggots and pupae will be killed if buried far down."

Even recently, Schøyen<sup>(24)</sup> recommends the sowing and ploughing-in of trap crops "as the larvae are thus buried in the ground," although Dobrovliansky<sup>(10)</sup> had pointed out that it was necessary to roll ploughed-in crops heavily to prevent emergence, having probably seen an account of the experiment of Krassiltchik and Vitkovsky<sup>(16)</sup>, in which they found that flies escaped freely from a glass vessel containing puparia covered with rammed soil, which was kept wet. Some preliminary experiments on a small scale were made in 1919-20 with the view of ascertaining whether the larvae could, under any conditions, complete their development, if buried with the host plant. The results of these experiments are given in the following synopses.

In all cases the presence of larvae in the plants was ascertained by previous examination of the stems, the control plants being treated in exactly the same way.



# SYNOPSIS VI. *Observations with Puparia.*

| No. of exp.   | Date of exp. | Source of puparia | No. of puparia used | Apparatus                                                                     | Type of soil    | Condition of soil                                    | Depth of burial in inches | Situation of apparatus       | Result                                                                                                                                                                                           |
|---------------|--------------|-------------------|---------------------|-------------------------------------------------------------------------------|-----------------|------------------------------------------------------|---------------------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 11            | 12. 8. 19    | Oat grains        | 20                  | Glass cylinder 5 ins. diam. netted above and below                            | Coral rag       | Moistened and sieved loosely, pressed on top by hand | 9                         | Cylinder sunk in garden soil | 8 flies emerged between 10-23 days = 40%                                                                                                                                                         |
| 12            | "            | "                 | 20                  | Glass jar 6 ins. diam. netted above                                           | "               | Saturated and rummed by hand every 3 ins.            | 9                         | "                            | Emergence from soil, nil<br>14 puparia recovered, 26, 9, 19<br>Emergence taken from 12 failed from 2                                                                                             |
| 13            | "            | "                 | 70                  | "                                                                             | —               | —                                                    | —                         | "                            | 56 flies emerged between 6-27 days = 80%                                                                                                                                                         |
| Control<br>14 | 23. 6. 20    | Oat plants        | 25                  | Farm drain pipe 3 ins. diam. observation chimney above and muslin cover below | Heatington sand | Dry                                                  | 9                         | Laboratory                   | 1 fly emerged after 17 days<br>19 puparia recovered 30, 7, 20<br>Emergence taken place from 13<br>" failed from 2<br>Dead chalcids found in 4<br>One fly found at depth of 5 inches, undeveloped |
| 15            | "            | "                 | 11                  | "                                                                             | "               | "                                                    | 7                         | "                            | No emergence<br>Examined 30, 7, 20<br>4 empty puparia and 2 flies recovered                                                                                                                      |
| 16            | "            | "                 | 25                  | "                                                                             | Coral rag       | "                                                    | 9                         | "                            | 1 cynipid emerged 16, 7, 20<br>Examined 28, 7, 20<br>16 empty puparia recovered<br>4 with dead larva recovered<br>1 with living Hymenopterous larva                                              |
| 17            | "            | "                 | 26                  | "                                                                             | —               | —                                                    | —                         | "                            | 17 flies between 3-9 days = 65.5%                                                                                                                                                                |
| Control       |              |                   |                     |                                                                               |                 |                                                      |                           |                              |                                                                                                                                                                                                  |

The larvae used in Exps. 1 and 2 were practically fully grown and it is not understood why they failed to pupate<sup>1</sup>. Later in the season, under similar conditions, flies emerged freely above ground. In Exps. 4

<sup>1</sup> Saturation of the soil would not kill the larvae for some time although it would probably hasten the rotting of the host plants and thus deprive the larvae of food. The subjoined notes illustrate the resistant powers of the immature stages to an unfavourable environment.

*Larvae.* Larvae of various ages (a full grown larva averages 3 mm. in length) were collected in the field and submerged, 1 in. deep, in dishes holding about an ounce of water, the dishes not being covered. The water supply was not renewed. A few larvae after submersion were removed and bred to the adult stage in young oat tillers.

| Date of submergence | Average length of larva in mm. | No. of days larvae survived submergence |         |                     |
|---------------------|--------------------------------|-----------------------------------------|---------|---------------------|
|                     |                                | Minimum                                 | Maximum | Average             |
| 28. 5. 20           | 2.3                            | 3                                       | 15      | 9.3<br>(3 larvae)   |
| 31. 5. 20           | 3.0                            | —                                       | 24      | 24<br>(1 larva)     |
| 26. 6. 20           | 2.6                            | 6                                       | 27      | 16.5<br>(11 larvae) |
| 16. 6. 20           | 2.4                            | 9                                       | 21      | 14.8<br>(15 larvae) |

On 16. 6. 20 six larvae were submerged and they were removed after 9 days, being then placed on young oat tillers. One larva died on the 10th day and another on the 13th day after submersion, but the other four were successful in completing metamorphosis. Pupation took place in 12, 12, 14 and 17 days and emergence of the adult in 29 (♂), 44 (chalcid), 33 (♂) and 29 (♀) days respectively. In another case a larva underwent ecdysis after 27 days submersion, but then failed to pupate.

The larvae were quiescent when submerged, but became active when removed from the water. Death was assumed when no sign of mandibular movement was visible under the microscope.

Ten larvae deprived of food and moisture lived for the minimum, maximum and average periods of 1, 4 and 2.9 days respectively, at room temperature.

*Puparia.* Twenty-four puparia were taken from oat stems on 28. 6. 20 and divided into batches A and B.

A. Twelve were placed in a dry chimney cage and gave 100 per cent. emergence by the end of 14 days.

B. Twelve were held submerged by cotton wool under water. No emergence took place by the end of 23 days and the water was then removed. After 32 days one female emerged. Three larvae failed to pupate, therefore emergence equalled 11.1 per cent.

The immature stages therefore exhibit considerable powers of endurance. Even the very young larvae are not readily killed. On 3. 6. 20, fifteen larvae varying in size from 0.15 to 0.8 mm. were placed 2 inches from the base of a clean oat plant, on the surface of the soil. After 2 days three larvae were recovered, two from tillers and one from a hole, gnawed in the stem 1½ inches above the soil. The remainder were caught by the greased rim of the pot. When migrating from one tiller to another or from plant to plant, the time of exposure in the field would be short, as they are capable of moving on damp soil at the rate of 1 inch per minute.

and 5 drying off would occur, with the result comparable with that obtained in Exps. 14-16.

When the soil was saturated with water and thoroughly compressed by hand, the emergence was nil (Exp. 12). That emergence of the flies from the buried puparia had taken place was proved by the recovery of the empty puparia. When the soil was loosely sieved in and pressed on top only (Exp. 11), a 40 per cent. emergence was obtained, which was half that of the controls. In the series of experiments with larvae, however, conducted under very similar conditions emergence practically equalled that of the controls.

It will be noticed that whereas flies emerged freely from a depth of 6-9 inches, under normal moisture conditions (Exps. 6, 9 and 11), they were unable to make their way a similar distance through a dry medium (Exps. 14-16), the dust from which probably choked their spiracles.

It is probable that only fully grown larvae succeeded in completing their metamorphosis, the young larvae being deprived of food owing to the rotting of the host plants.

It seems fair to conclude that ploughing-in a badly infested crop would fail to control the pest effectively. Subsequent rolling, on heavy land, would probably form a crust of sufficient density to prevent emergence on a large scale, but not on medium or light land.

Ploughing alone would check the development of larvae in their early stages owing to the destruction of the food supply, but would have to be conducted at a time when the attack would not be readily discernible.

#### EFFECT OF MANURIAL TREATMENT.

Vassiliev (27) conducted some experiments in 1911 to show that the application of mineral manures nullified the damage due to frit and concluded that under optimum conditions, produced by the application of phosphorus and nitrogen, frit-fly had no marked economic influence if the degree of infection was limited to 40 per cent. This experiment was repeated last season in its essential features with duplicate plots of area one-twelfth of an acre each, "Excelsior" oats being drilled in on 4.3.20. Strips through the centres of the plots were examined, 955 being the average number of plants handled in each case. As the experiment is not original, for convenience of comparison the results are meant and presented synoptically on the plan adopted by Collin (8), in whose paper Vassiliev's figures are quoted.

SYNOPSIS VII. *Manurial Treatment.*

Rate of manuring per acre in Vassiliev's experiments:

Soluble phosphorus 16 lbs. in the form of superphosphate. Potassium 55·8 lbs. Nitrogen 21·2 lbs. in the form of saltpetre.

Rate of manuring per acre in present experiment:

Soluble phosphorus 37·6 lbs. in the form of basic slag.

Potassium 27·2 „ „ kainite.

Nitrogen 23·0 „ „ sulphate of ammonia.

The slag and kainite were worked into the ground on Feb. 25th before sowing and sulphate of ammonia was applied as a top dressing on April 22nd.

| <i>Vassiliev's experiment.</i>            |                      |                    |                      | <i>Present experiment.</i>           |                    |                     |                          |                 |
|-------------------------------------------|----------------------|--------------------|----------------------|--------------------------------------|--------------------|---------------------|--------------------------|-----------------|
|                                           | % of plants attacked | % of plants killed | Yield per acre grain | % of plants attacked                 | % of plants killed | % of grains damaged | Yield <sup>1</sup> grain | Straw and chaff |
| Unmanured                                 | 43                   | 21                 | 33·7                 | 48·8                                 | 9·2                | 16                  | 27·1                     | 30·9            |
| Phosphorus }<br>Potassium }               | 46                   | 17                 | 37·5                 | 52·2                                 | 2·9                | 14                  | 30·2                     | 30·7            |
| Phosphorus }<br>Nitrogen }                | 35                   | 5·5                | 47·1                 | 50·4                                 | 1·4                | 14                  | 29·6                     | 37·7            |
| Nitrogen }<br>Potassium }                 | —                    | —                  | —                    | 48·8                                 | 0·3                | 10                  | 32·4                     | 37·7            |
| Phosphorus }<br>Nitrogen }<br>Potassium } | 41                   | 7                  | 49·5                 | 45·8                                 | 1·8                | 14                  | 32·2                     | 37·2            |
| Increase in yield with all manures        |                      |                    | 47 %                 | { 19 % grain<br>21 % straw and chaff |                    |                     |                          |                 |
| Percentage killed on nitrogen plots       |                      |                    | 6·2                  | 1·2                                  |                    |                     |                          |                 |
| Percentage killed on unmanured plots      |                      |                    | 21·0                 | 9·2                                  |                    |                     |                          |                 |

The manurial value will only show in the increased yield and the reduced percentage of plants killed. The results of the two experiments are very similar, even though, except for nitrogen, the rates of manuring are different. The percentage of plants attacked necessarily includes plants with attacked tillers, and as these are liable to be infested throughout the season, it is not surprising that this percentage is practically the same on all the plots.

Phosphorus and potassium alone have very little value. The nitrogen plots confirm the accepted opinion that the stimulus of nitrogen tends

<sup>1</sup> The yield in this experiment was the rate per acre, the grain being reckoned in bushels of 42 lbs. and the straw plus chaff in cwts., the figures being derived from the analysis of the contents of circles 4 feet in diameter. I am indebted to Professor Somerville for the provision of the necessary labour and materials for the conduction of this experiment and also for the yield figures.

to limit the damage by decreasing the percentage of plants killed. The percentage of grains damaged was unaffected (the grain in turn being always subject to attack), but on the nitrogen plots the plants were more forward and therefore produced grain and straw of slightly greater bulk.

Although the general infestation was about equal in both experiments the severity of the attack, in the present experiment, was evidently not so great in the first instance, as the percentage of plants killed on the unmanured plots was only 9 per cent. as against 21 per cent.<sup>1</sup> It was to be expected therefore that the percentage increase in yield would also be somewhat less. The cost of application of these manures was not covered by the increased yield.

Advantage was taken of an experiment conducted by Professor Somerville last season to test the relative advantages of sulphate of ammonia, nitrate of lime and nitrolim as nitrogen conveyers, if used for limiting frit attack. The procedure of sampling (average of plants examined per plot, 393) and estimation of yield was as above, and from the synopsis below it will be seen that although nitrate of lime was slightly better than sulphate of ammonia, while nitrolim was much the reverse, none of the three gave a high yield with a low percentage of plants killed. It should be pointed out that sodium nitrate was not available for either of these experiments.

#### SYNOPSIS VIII. *Treatment with Nitrogenous Manures.*

"Excelsior" oats drilled in on 10. 3. 20, on plots adjacent to one another.

Plots manured 19-21. 4. 20. Rate of manuring per acre in terms of nitrogen: sulphate of ammonia plot, 17.2 lbs.; nitrate of lime plot, 18.2 lbs.; nitrolim plot, 22.4 lbs.

|                     | Percentage<br>of plants<br>attacked | Percentage<br>of plants<br>killed | Percentage<br>of grain<br>damaged | Yield per acre |             |
|---------------------|-------------------------------------|-----------------------------------|-----------------------------------|----------------|-------------|
|                     |                                     |                                   |                                   | Grain          | Straw chaff |
| Sulphate of ammonia | 73.6                                | 11.4                              | 11                                | 36.3           | 30.2        |
| Nitrate of lime ... | 69.2                                | 9.9                               | 15                                | 42.5           | 31.9        |
| Nitrolim ... ..     | 72.8                                | 10.6                              | 16                                | 29.4           | 20.5        |

It is considered that the nitrogen, from the nitrate of lime, was as readily available as it would have been if sodium nitrate had been applied as a top dressing, in place of nitrate of lime. The manures were applied before the flies emerged in appreciable numbers, yet even this early

<sup>1</sup> The soil of the plots on which Vassiliev worked is recorded as being very deficient in phosphorus and nitrogen, which probably accounts for the high percentage of plants killed on his control plots and the high percentage increase in yield.

application was not effective. Nitrogenous manures are not likely to repay their cost when used on average land in England, while phosphorus and potassium alone have no value in limiting damage due to frit-fly.

While collecting these data the degrees of infection were estimated (1) near the hedge and (2) about the centre of plot B (Fig. 1), an average of 328 plants being examined in each case. The percentages of plants attacked and killed near the hedge were 73.5 and 6.7 and in the centre of the plot 61.8 and 1.3 respectively.

Baranov<sup>(3)</sup> states that the flies attack chiefly on the boundary strips round fields to a width of 9 feet, the central areas being seldom damaged. From the figures given above, it will be seen that this is probably not usually the case in this country. Although the damage in the central areas is distinctly less than on the boundary strips it is still very considerable.

#### PARASITES.

Certain Hymenoptera, not previously recorded as being parasitic on the frit-fly, have been reared from puparia collected for experimental purposes<sup>1</sup>. There is, of course, a slight element of doubt as to the exact identity of the host in such a genus as *Oscinella*, but from the hundreds of puparia collected from oat plants, no other species than *O. frit* emerged. It is practically certain therefore that *O. frit* was the host of these parasites either directly or indirectly.

In the two seasons 1919 and 1920 parasitism was not at all pronounced and also comparatively few *Ichneumonidae* were collected while sweeping.

Out of one batch of fifteen puparia collected on 16. 7. 19 at random, from oat stems in the field, eight parasites emerged, but on no other occasion was a similar degree of infection noticed, and this batch was probably abnormal.

The few parasites (or hyperparasites) which have been reared are distributed among the parasitic Hymenopterous families as follows: **Proctotrypidae**, one specimen unidentified to date; **Braconidae**, *Chasmodon apterus*, Nees (emerged Sept. 1919); **Cynipidae**, *Psichaera* (Först.) spp. (emerged Sept. 1919); two different species of this subgenus have been reared, and they are of interest because other members of the genus *Eucnida* are known to be parasitic on Diptera; *Aphidius*

<sup>1</sup> I am indebted to Mr G. C. Lyle and the Rev. J. Waterston for the identification of these insects, as far as is possible at present. The latter gentleman hopes to publish a paper shortly on the more interesting species, which are not yet completely identified.

*granarius* (emerged 16. 8. 20); **Chalcidae**, *Dicyclus fuscicornis*, Walker (emerged Sept. 1919) and specimens of at least two other genera, at present unidentified.

## SUMMARY.

1. The adult frit-fly is prevalent in the field throughout the year except for the period November to April.

2. There are periods of high prevalence, which are probably limited by meteorological conditions.

3. High prevalence seems to be associated with high temperatures and emergence with rainfall, and should not be associated with any particular brood or generation.

4. It is very probable that normally four generations are produced in one year and that the fly is double-brooded.

5. The periods between the emergence of successive generations are about 50 days in spring, 35 days in summer and 230–250 days in winter.

6. *Arrhenatherum avenaceum*, *Festuca pratensis*, *Lolium italicum*, *Lolium perenne* and *Poa annua* can be utilised as host plants in the summer and *Alopecurus myosuroides*, *Arrhenatherum avenaceum*, *Hordeum pratense*, *Lolium italicum* and *perenne* in the winter.

7. In captivity, the longevity of the imago averages 50 days in spring and in summer.

8. Ploughing-in and rolling would only control the pest on heavy land.

9. Nitrogenous manures are not likely to repay the cost of application on average land in England.

10. The following Hymenopterous parasites are recorded, for the first time, as attacking frit-fly: *Chasmodon apterus*, Nees, *Psichaera* (Först.) spp., *Aphidius granarius* and *Dicyclus fuscicornis*, Walker.

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